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(57) Abstract

Arrangements for preferred air filter constructions are provided. The arrangements generally include a media pack having the first and second opposite liners, with a media construction positioned therebetween. Preferred media constructions include an upstream depth media portion and a downstream pleated barrier media portion are included. In certain preferred embodiments, a second depth media portion positioned downstream from the pleated barrier media portion, is provided. In addition, engine air intake systems including an engine having an air cleaner and an air filter element positioned within the air cleaner are provided. Methods of assembly and use are also presented.

AIR FILTRATION ARRANGEMENTS AND METHODS

Field of the Invention

The present invention relates to filter arrangements and methods. More specifically, it concerns arrangements for filtering particulate material from gas flow streams, for example, air streams. The invention also concerns methods for achieving the desirable removal of particulate material from such gas flow streams.

The present invention is an on-going development of Donaldson Company Inc., of Minneapolis, Minnesota, the assignee of the present invention. The disclosure concerns continuing developments related, in part, to the subjects characterized in U.S. Patents: 5,082,476, issued January 21, 1992; 5,238,474, issued August 24, 1993; 5,364,456, issued November 15, 1994; 5,423,892, issued June 13, 1995; and 5,622,537, issued April 22, 1997; as well as pending U.S. applications Serial Number 08/690,875, filed July 31, 1996; Serial Number 08/799,424, filed February 12, 1997; Serial Number 08/708,153, filed July 31, 1996; and Serial Number 08/827,475, filed March 27, 1997. Each of the patents and pending applications identified in the previous sentence is also owned by Donaldson, Inc., of Minneapolis, Minnesota; and, the complete disclosure of each is incorporated herein by reference.

Background of the Invention

Gas streams often carry particulate material therein. In many instances, it is desirable to remove some or all of the particulate material from a gas flow stream. For example, air intake streams to engines for motorized vehicles or power generation equipment, gas streams directed to gas turbines, and air streams to various combustion furnaces, often include particulate material therein. The particulate material, should it reach the internal workings of the various mechanisms involved, can cause substantial damage thereto. It is therefore preferred, for such systems, to remove the particulate material from the gas flow upstream of the engine, turbine, furnace or other equipment involved.

In other instances, production gases or off gases from industrial processes may contain particulate material therein, for example, those generated by

the process. Before such gases can be, or should be, directed through various downstream equipment and/or to the atmosphere, it may be desirable to obtain substantial removal of particulate material from those streams.

A variety of air filter or gas filter arrangements have been developed for particulate removal. However, in general, continued improvements are sought.

Summary of the Invention

Herein, general techniques for the design and application of air cleaner arrangements are provided. The techniques include preferred filter element design, as well as the preferred methods of application and filtering.

In general, the preferred applications concern utilization, within an air filter, of depth media arrangements or combinations of depth media and barrier media arrangements, to advantage.

In certain applications of the techniques described herein, the filter element is provided with a unique support structure positioned therein, in order to operate to facilitate radially sealing between the filter element and an air flow tube. The preferred support ring includes a perimeter area with a plurality of outwardly projecting feet thereon, oriented for positioning under an end cap during assembly.

In a wide variety of applications of the techniques described herein, it is possible to develop and construct filter elements which, by comparison to many conventional filter elements, are relatively small in size, for example with respect to approach velocity, overall media volume, or media pack thickness. Preferred approaches to the design of such arrangements, are described herein. They can be utilized in a wide variety of applications including: on-road and off-road; and, industrial equipment. Approaches for light duty, medium duty and heavy duty are provided.

Brief Description of the Drawings

Fig. 1 is a cross-sectional view of an embodiment of an air cleaner, including an adapter ring construction, in accordance with certain applications of the present invention.

Fig. 2 is a fragmented, side elevational, partial cross-sectional view of the adapter ring construction used in the air cleaner depicted in Fig. 1; in Fig. 2 certain optional strut constructions and other features being shown in phantom.

Fig. 2A is a fragmented, side elevational, partial cross-sectional schematic view of an alternate embodiment of an adapter ring construction useable in the air cleaner depicted in Fig. 1.

Fig. 2B is a schematic plan view of the adapter ring construction depicted in Fig. 2A.

Fig. 3 is a partially schematic, fragmented, cross-sectional view taken along the line 3-3 of Fig. 1.

Fig. 4 is a schematic perspective view of a filter element positioned within an air cleaner housing (shown in phantom) and depicting air flow in a forward-flow system.

Fig. 5 is a side elevational view, partially cross-sectioned, of an air cleaner housing with a filter element oriented therein, the air filter element being a different air filter element than that depicted in Fig. 1.

Fig. 6 is a fragmented, cross-sectional view depicting a preferred endcap sealing area profile for the filter element used in the arrangement of Fig. 5.

Fig. 7 is a schematic view of an example media pack.

Fig. 8 is an alternate schematic view of an example media pack.

Fig. 9 is a graph indicating a relationship among: the dimensions of air cleaner environment components; air flow; and, restriction, in accordance with certain aspects of the present invention.

Fig. 10 is a schematic view of a system having an engine with an air intake system and an air cleaner therein.

Detailed Description

Herein, the term "air cleaner" will be used in reference to a system which functions to remove particulate material from an air flow stream. The term "air filter" references a system in which removal is conducted by passage of the air, carrying particulate therein, through filter media. The term "filter media" or "media" refers to a material or collection of material through which the air passes, with a

concomitant deposition of the particles in or on the media. The term "surface loading media" or "barrier media" refers to a system in which as the air passes through the media, the particulate material is primarily deposited on the surface of the media, forming a filter cake, as opposed to into or through the depth of the media. The term "depth media" refers to a media in which a substantial majority of particle deposition occurs throughout the media depth, as opposed to primarily on the surface of a filter cake.

The term "precleaner" is generally used to refer to a system which generates some separation of particulate material from an air flow stream, but not as a result of passage through a filter media. A precleaner may use, for example, cyclonic separation methods to cause particulate material to drop out of a moving air stream. A precleaner can be a separate piece of equipment from an air cleaner having filter media therein; or a precleaner can be a portion of an air cleaner housing design in which cyclonic or similar separation occurs prior to the air stream passing through media operably contained in the air cleaner. In general, each of these types of systems has been used in a variety of conventional constructions. The term "operably" in this and similar contexts is meant to refer to media appropriately positioned for a filtering flow of air therethrough.

Herein the term "filter element" is generally meant to refer to a portion of the air cleaner which includes the filter media therein. In general, a filter element will be designed as a removable and replaceable, i.e. serviceable, portion of the air cleaner. That is, the filter media will be carried by the filter element and be separable from the remainder portion of the air cleaner so that periodically the air cleaner can be rejuvenated by removing a loaded or partially loaded filter element and replacing it with a new, or cleaned, filter element. Preferably, the air cleaner is designed so that the removal and replacement can be conducted by hand. By the term "loaded" or variants thereof in this context, reference is meant to an air cleaner which has been on-line a sufficient period of time to contain a significant amount of trapped particles or particulates thereon, for example, at least a weight gain of 5%. In many instances, during normal operation, a filter element will increase in weight, due to particulate loading therein, of two or three times (or more) its original weight.

Herein, in some instances references will be made to "on-road" and "off-road" elements. In general, a typical difference between on-road and off-road element design and use concerns the presence of a "safety element". More specifically, in many instances, off-road filter elements are utilized in association with the safety elements. For forward flow arrangements, the safety element is generally a cylindrical element that is positioned inside of the "primary" element during use. Safety elements are described in greater detail, in Section L below. The term "primary", in this and similar contexts, is meant to refer to the element which conducts the majority of particle collection, in normal use. Typically, it will be the more "upstream" element, if a safety element is involved. Herein, when the term "element" is used, reference is meant to the primary element, if a safety element is involved. Reference to safety elements will generally be specific by the use of the term "safety".

In the filter art, elements are often referenced with respect to whether they are constructed for "light duty", "medium duty" or "heavy duty" application. With respect to on-road, the specification generally relates to the minimum expected lifetime for the element, in terms of miles of operation of the vehicle involved. Typical light duty applications or elements are constructed and arranged to operate effectively for at least 20,000 miles, typically at least 30,000 miles. Medium duty elements are generally ones constructed and arranged to operate for an average of at least 40,000 miles, typically at least 50,000 miles. Heavy duty elements are elements constructed and arranged to operate for at least about 90,000 miles, typically 100,000 miles or longer. Of course, the characterization is on a continuum. An element designed for 80,000 miles, for example, might be classified by some as a heavy duty element.

Off-road elements are also generally characterized as light duty, medium duty or heavy duty elements. For off-duty specifications, however, the definitions are generally with respect to expected hours of use, prior to filter element change. In general, light duty elements, for off-road use, are elements constructed and arranged for an expected operation period of at least about 90 hours and typically at least 100 hours without changeout; medium duty elements are generally constructed and arranged for operation in the field for at least about 225 hours,

typically at least 250 hours, without changeout; and, heavy duty elements are generally elements constructed and arranged to be used in the field for at least about 450 hours, typically at least 500 hours, without changeout. Again, a continuum is involved.

A. Contaminant classes and characteristics

In general, contaminants to be separated by air cleaners of the general type of interest herein can be characterized as falling into two general classes, depending upon characteristic or source. The two general classes or types are as follows:

1. Environmental, airborne, particles; and,
2. Particles "thrown up" into the air as a result of equipment operation, industrial operation, etc.

By presenting the general descriptions of the two classes indicated above, there is no intent to suggest that a "bright" dividing line exists. Some types or sources of particles could be viewed as belonging in either class (i.e., both). Herein, the two classes may sometimes be referred to as "class" 1 or 2 or "type" 1 or 2, respectively.

Typically, environmental airborne particles (class 1 or type 1 particles) are of the following types: pollen or other organic fines from plants; fine dust carried in air; salts carried in air near marine environments; and fine carbon particles resulting from various combustion processes, for example, operation of engines. In typical samplings, the vast majority of such particles, both by number and weight, are typically less than ten microns in size. (The term "size" in this context referring to a longest cross-sectional dimension of the particle.) In typical environmental dust evaluations, such particles are observed to distribute in a size range between sub micron and about 10-12 microns, usually 1-10 microns with two "peaks" or "nodes" in the distribution pattern, based on weight; a first occurring at less than two microns, typically in the 0.1-1.0 micron range; and, a second in about the 5 to 12 micron range. In some environmental evaluations, it has been observed that the distribution of particles, by weight, with respect to each "node" is between

about 40-60 percent. That is, the samplings generally indicate about 40-60 percent, by weight, of each subclassification.

The second type or classification (class 2 or type 2) of particles, generally, is meant to refer to particles that are not necessarily so fine that they generally remain airborne, but, rather, are of a type "tossed up" or "thrown up" into the environment as a result of equipment operation and which may take a substantial period of time to settle. Examples of such contaminants are: the dust cloud which follows a rapidly moving vehicle on a dirt road or in an off-road environment; the dust cloud generated at a construction site by a rock crusher, road grader or similar equipment; the dust or dirt cloud generated in the field by operation of tractors or similar agricultural equipment; dust clouds generated by equipment use or wind in a desert environment; and, particulates resulting from operation of some industrial processes. In general, if one evaluates and classifies such materials, the majority, by weight and often also by number, of the particles therein is often of a relatively large size, in many instances 10 microns or larger.

In many ways, carbon particles or similar contaminants can be viewed as belonging in both types of classes. For example, carbon particles generally result from operation of equipment, more specifically, engine operation. Although carbon particles are generally very fine, they do tend, in some environments, to clump or agglomerate, thereby forming larger particles. Also, in some instances, they do settle out of the air, in time, as a soot or tar. In spite of this, in general with respect to appropriate filtration techniques, it is typically convenient to classify carbon particles as being of the environmental, airborne, relatively fine particle, type.

B. <u>Air Cleaner Design-Dependency on Environment of Use</u>

In general, a factor in determining air cleaner or air filtration design, is the environment of proposed use. For example, if the equipment is to be heavily used in an environment in which a high percentage of the contaminant encountered will be of the very fine, sub micron, carbon particle type, it will typically be necessary and desirable to develop an air cleaner which is very efficient with respect to filtering out such fine particles. An example of such an environment would be an

inner city environment; and, the equipment would typically be: an air cleaner for a bus or delivery truck to be operated almost exclusively in such an environment; or, a generator air cleaner intake or gas turbine air cleaner intake to be used in such an environment. Of course, such an air cleaner may be subject to a substantially shorter lifetime if it were used for a substantial period of time in an environment in which larger particles, which could plug or occlude the filter rather rapidly, are encountered. Thus, in some instances, a well-designed inner city bus or delivery truck filter would not be appropriate for use at a mining or construction site, with large amounts of larger particle dust material carried in the air, due to reduced filter lifetime. Herein, inner city environments (or similar environments) of the type characterized in this paragraph will sometimes be referred to as Type A environments.

A second type or intermediate type (Type B) of air cleaner environment is the type generally encountered by over-the-highway trucks and similar equipment. Such air cleaners generally encounter relatively clean air (by comparison to off-road or construction sites), with airborne particles of the first classification type discussed above, a majority of the time. However, with some reasonable and expected frequency, such air cleaners are used in environments in which substantial "class 2" type dust is encountered, for example, on dirt roads, or when travel in a dust storm is involved, or when travel through or near construction sites, agricultural work sites or mining sites is involved. If the air cleaner in such equipment is optimized for inner city fine particle cleaning, it may prematurely occlude when the equipment encounters environments having a substantial amount of the Type 2 classification of contaminant.

A third type of an environment (Type C) in which air cleaning equipment is used, is the high large particle dust, or similar contaminant, environment such as where mining equipment, construction equipment, off-road vehicle equipment, or agricultural equipment is operated. Such equipment is used for substantial periods of time in environments in which large amounts of larger particle materials are carried in the air to be filtered by the air cleaning system. In many instances, especially in such environments, the overall air cleaner system of equipment includes a “precleaner” in addition to a filter element. Again,

precleaners, generally comprise equipment which operate to provide some level of separation of air-carried contaminant from an air flow stream, prior to (or without) direction of the air through a filter media. A cyclonic separator used upstream from an air filter is a precleaner. As a result of precleaner use, a preclassification of the particulate material, with removal of a large amount of the larger particles carried therein, occurs. Nevertheless, in such environments, and with such equipment, even when a precleaner is used, the air filter media through which the air is eventually directed for filtration, will generally see a higher percentage of larger particles, than equipment normally used in the Type A and Type B environments discussed above. Also, in many instances the use of a precleaner is not desirable.

In general, in marine environments, an added type of contaminant is salt or minerals carried in the air, resulting from wind carried evaporation of the river water, lake water or ocean water involved. These particles can vary over a relatively large size range. Similarly, industrial processes, from which particles are carried in air flow streams, can involve generation of particles over relatively wide size range.

C. <u>Air cleaner Design-OEM Specifications; Terms</u>

In general, specifications for the performance of an air cleaner system are, in many instances, generated by the preferences of the original equipment manufacturer (OEM) for the engine involved and/or the OEM of the truck or other equipment involved. For example, manufacturers of engines such as Cummins, Caterpillar, John Deere, Mercedes Benz, Nissan, Volvo, Isuzu, etc. often have specifications for air cleaner performance as it relates to engine performance, warranty or maintenance; and, equipment manufacturers such as Caterpillar, Freightliner, Case, Peterbilt, Volvo, Mack, Komatsu, etc. also may have engineering specifications for air cleaner operation, again typically related to warranties, performance or service.

While a wide variety of specifications may be involved, some of the major ones are the following:

1. Engine air intake need (rated flow)
2. Initial Restriction

3. Initial efficiency
4. Average or overall operating restriction
5. Overall efficiency
6. Filter service life

The engine air intake need is a function of the engine size, i.e. displacement and rpm at maximum, full or "rated" load. In general, it is the product of displacement and rated rpm, modified by the volumetric efficiency, a factor which reflects turbo efficiency, duct efficiency, etc. In general, it is a measurement of the volume of air, per unit time, required by the engine or other system involved, during rated operation or full load. While air intake need will vary depending upon rpm, the air intake requirement is defined at a rated rpm, often at 1800 rpm or 2100 rpm for many typical truck engines. Herein this will be characterized as the "rated air flow" or by similar terms. In general, principles characterized herein can be applied to air cleaner arrangements used with systems specified for operation over a wide range of ratings or demands, including, for example, ones in the range of about 50 cubic feet/min. (cfm) up to 10,000 cfm. Such equipment includes, for example: automotive engines, pickup trucks and sport utility vehicle engines, engines for small trucks and delivery vehicles, buses, over-the-highway trucks, agricultural equipment (for example tractors), construction equipment, mining equipment, marine engines, a variety of generator engines, and, in some instances, gas turbines. (It is noted that in some instances, average air flow, which is the expected average engine demand rather than rated demand, is referenced by OEMs in specifications.)

The specific designs and applications will vary, depending upon the specific equipment and the environment of use anticipated.

Air cleaner overall efficiency is generally a reflection of the amount of "filterable" solids which pass into the air cleaner during use, and which are retained by the air cleaner. It is typically represented as the percentage of solids passing into the air cleaner which are retained by the air cleaner in normal use, on a weight basis. It is evaluated and reported for many systems by using SAE standards, which techniques are generally characterized in U.S. Patent 5,423,892 at Column 25, line 60- Column 26, line 59; Column 27, lines 1-40. A typical standard used is SAE J726, incorporated herein by reference.

With respect to efficiency, engine manufacturer and/or equipment manufacturer specifications will vary, in many instances, with efficiency demands (based on either SAE J726 or field testing) for overall operation often being set at 99.5% or higher, typically at 99.8% or higher. In some instances, the minimum efficiency is specified to the tenths place, or even the hundredths place, in the percent reported. For example, an engine manufacturer could consider a specified efficiency of 99.88% to not be satisfied by an actual tested efficiency of 99.87%. Thus, some (otherwise relatively minor) structural modifications in an air cleaner system in order to accomplish a 0.01 percentage point increase in overall efficiency can be quite significant in product desirability. With typical vehicle engines having air flow demands of 500 cfm or above, specifications of 99.8% overall average, or higher, are not uncommon.

Initial efficiency is the measurable efficiency of the filter when it is first put on line. As explained in U.S. Patent 5,423,892 at Column 27, lines 1-40, especially with conventional pleated paper (barrier type or surface-loading) filters, initial efficiency is generally substantially lower than the overall average efficiency during use. This is because the "dust cake" or contaminant build-up on the surface of such a filter during operation, increases the efficiency of the filter. Initial efficiency is also often specified by the engine manufacturer and/or the vehicle manufacturer. With typical vehicle engines having air flow demands of 500 cfm or above, specifications of 98% or above (typically 98.5% or above) are common.

Restriction is the pressure differential across an air cleaner or air cleaner system during operation. Contributors to the restriction include: the filter media through which the air is directed; duct size through which the air is directed; and, structural features against which or around which the air is directed as it flows through the air cleaner and into the engine. With respect to air cleaners, initial restriction limits are often part of the specifications and demands of the engine manufacturer and/or equipment manufacturer. This initial restriction would be the pressure differential measured across the air cleaner when the system is put on line with a clean air filter therein and before significant loading occurs. Typically, the specifications for any given system have a maximum initial restriction requirement.

In general, engine and equipment manufacturers design equipment with specifications for air cleaner efficiency up to a maximum restriction. As reported in U.S. Patent 5,423,892, at Column 2, lines 19-29; and, column 6, line 47, column 7, line 3, the limiting restriction: for typical truck engines is a pressure drop of about 20-30 inches of water, often about 25 inches of water; for automotive internal combustion engines is about 20-25 inches of water; for gas turbines, is typically about 5 inches of water; and, for industrial ventilation systems, is typically about 3 inches of water.

As is explained at the portions of the '892 patent referenced in the previous paragraph, a typical operational "lifetime" for an air cleaner system or air filter element, is the period of time the air cleaner can operate in the environment of concern, without reaching the limiting restriction. In many types of equipment, restriction indicators are used to indicate when it is time to change filters. In other instances, equipment manufacturers will specify, for ordinary performance, maintenance intervals for air filter servicing, i.e. service lifetime in miles or hours of operation, and will require air cleaners which will regularly, reproducibly and predictably operate without reaching the limiting or lifetime restriction, in a time period shorter than the ordinary expected service lifetime or service interval.

D. Air Cleaner System Design-Air Cleaner Design Variables to Meet Specification

In general, some of the principal variables of concern in air cleaner design in order to develop systems to meet the types of specifications characterized in the previous section, are the following:

1. filter media type, geometry and efficiency;
2. air cleaner shape and structure; and
3. filter element size.

For example, conventional cellulose fiber media or similar media is generally a "barrier" filter. An example is paper media. In general, the operation of such media is through surface loading, i.e., when air is directed through the media, the surface of the media acts as a barrier or sieve, preventing passage of particulate material therethrough. In time, a dust cake builds on the surface of the media,

increasing media efficiency. In general, the "tightness" or "porosity" of the fiber construction determines the efficiency, especially the initial efficiency, of the system. In time, the filter cake will effect (increase) the efficiency.

In general, such media is often defined or specified by its permeability. The permeability test for media is generally characterized in U.S. Patent 5,672,399 at Col. 19, lines 27-39. In general, it is the media face velocity (air) required to induce a 0.50 inch water restriction across a flat sheet of the referenced material, media or composite. Permeability, as used herein, is assessed by a Frazier Perm Test, according to ASTM D737 incorporated herein by reference, for example using a Frazier Perm Tester available from Frazier Precision Instrument Co., Inc., Gaithersburg, Md., or by some analogous test.

The permeability of cellulose fiber media used in many types of engine filters for trucks having rated air flows fibers of 500 cfm or more manufactured by Donaldson Company, is media having a permeability of less than about 15 fpm, typically around 13 fpm. In general, in the engine filtration market, for such equipment, a variety of barrier media (pleated media) having permeability values of less than about 25 fpm, and typically somewhere within the range of 10-25 fpm, have been widely utilized by various element manufacturers.

Another type of media referenced above, discussed in detail in U.S. Patent 5,423,892, is depth media. Depth media is generally a structure which is quite open and porous, but relatively deep. Such media does not generally primarily operate through surface or barrier filtering, but rather by a variety of particle trapping mechanisms relating to particles encountering parts of the media as the carrier gas makes its way through the depth media. The majority of the load in such systems, then, does not occur on the most upstream surface as a filter cake, but, rather, is more greatly distributed through the depth of the media. A variety of such media constructions are described in the '892 patent, and some are characterized hereinbelow. A particular type of depth media characterized in detail in the '892 patent, and below, is fibrous depth media.

Other types of media usable in air cleaner systems, including some using principles disclosed herein include: open cell foam, for example polyurethane foam media available from foam suppliers such as BASF Corporation, Wyandotte,

Michigan; or, 3M, St. Paul, Minnesota; and, in some instances, microporous media. For example, stretched polytetrafluoroethylene (PTFE) membranes comprising nodes interconnected by fibrils, of the type generally manufactured by or under the direction of W. L. Gore and Associates, Inc., of Newark, Delaware and marketed under the designation Gore-Tex®; and, the PTFE material manufactured by Tetratec, a division of Donaldson Company Inc., and marketed under the trade designation Tetratex®, are microporous membranes. Techniques for manufacture of such microporous membranes are generally provided in U.S. Patents 3,953,566; 4,187,390; 4,110,239; and 5,066,683, incorporated herein by reference. In many instances, such membranes are utilized in air cleaner filter constructions wherein the membrane is laminated to a substrate, for example, a scrim; or, wherein the membrane is positioned between various substrates, such as two layers of felt or scrim. In general, PTFE membranes, or similar microporous membranes, operate as surface loading or barrier filters. (Open cell foam membranes, on the other hand, typically operate as depth media.)

Yet another filtration media, which utilizes spaced fine fiber structures, is characterized in Donaldson U.S. Patent No. 5,672,399 incorporated herein by reference, and commonly assigned U.S. Application Serial Number 08/935,103 filed September 29, 1997, incorporated herein by reference. Such a material could be viewed as a hybrid between a depth media type structure and a surface-loading structure. That is, the particles will be distributed through the depth of such an arrangement, but the fine fiber layers will each generally operate, in part, as a form of barrier, with, in some instances, the spacing material operating primarily to separate the fine fiber layers and to allow for load. Such media can also be used in selected arrangements including principles as characterized herein.

With respect to media geometry, in general, with barrier filters, or the hybrid arrangements of '399 and USSN 08/935,103, preferred geometries are typically pleated, cylindrical, patterns. Such cylindrical patterns are generally preferred because they are relatively straightforward to manufacture, use conventional filter manufacturing techniques, and are relatively easy to service. The pleating of surface loading media increases the surface area positioned within a given volume. Generally, major parameters with respect to such media positioning

are: pleat depth; pleat density, typically measured as a number of pleats per inch along the inner diameter of the pleated media cylinder; and, cylindrical length or pleat length. In general, a principal factor with respect to selecting media pleat depth, pleat length, and pleat density, especially for barrier (non-hybrid) arrangements is the total surface area required for any given application or situation. Such principles would apply, generally, to such barrier media: as cellulose fiber or paper media; to PTFE microporous media as characterized above; and, to similar barrier type arrangements.

Herein, reference will sometimes be made to "media volume". In the instance of a cylindrical pleated barrier filter, media volume will generally be the volume of the portion of the cylinder defined between the inner pleat tips and the outer pleat tips. (An analogous formula would apply if the construction were not cylindrical.) In those instances of pleated paper filters in which the pleated media is secured between adjoining inner and outer cylindrical liners, generally the media volume or filter volume is the volume enclosed between the two liners and through which the pleated media extends. In such systems, the media volume can be readily calculated by determining the cylindrical volume defined by the outer liner and subtracting from it the cylindrical volume defined by the inner liner.

Depth media systems, or systems using a combination of barrier media and depth media, as indicated in U.S. Patent 5,423,892, are less restricted with respect to geometry than are strictly barrier systems. For example, attention is directed to U.S. Patent 5,423,892 at column 18, line 60- column 21, line 68. However, in general, to date such arrangements, especially with respect to vehicle filters, have been made in about the same size and shape (typically having at least about 66% of the same media volume and generally more) as pleated media arrangements for similar applications. Thus, in those instances in which the entire media construction is positioned between inner and outer liners, the media volume is generally the cylindrical volume defined between the inner and outer liners, and can be calculated in the same manner as indicated above.

In addition, spaced fine fiber arrangements, such as described in U.S. Patent 5,672,399 incorporated herein by reference, can be used in a variety of

configurations, as indicated in that reference. However, they were specifically designed to be useable as preferred pleated constructions.

It is noted that a variety of composites or hybrid arrangements are possible, in which more than one type of media is used in a single air cleaner. Such arrangements are described, for example, in U.S. Patent 5,423,892, see for example the descriptions in connection with Figs. 2, 3, 6 and 9-11. More specifically, at these locations combinations involving composite systems with both pleated cellulose media and depth media are presented. In commonly assigned U.S. Patent Application Serial No. 08/678,301 filed July 11, 1996, incorporated herein by reference, combinations involving pleated media, foam depth media and cellulose fiber media are also presented.

In U.S. Patent 5,672,399, incorporated herein by reference, and commonly assigned U.S. Application Serial No. 08/935,103 filed September 29, 1997, incorporated herein by reference, arrangements involving combinations of spaced fine fiber structures with a variety of alternate and additional filter materials, are suggested.

With respect to efficiency, principles vary with respect to the type of media involved. For example, cellulose fiber or similar barrier media is generally varied, with respect to efficiency, by varying overall general porosity or permeability. Also, as explained in U.S. Patent 5,423,892 and 5,672,399, the efficiency of barrier media can be modified in some instances by oiling the media and in others by applying, to a surface of the media, a deposit of relatively fine fibers, typically less than 5 microns and in many instances submicron sized (average) fibers. With respect to fibrous depth media constructions, for example, dry laid fibrous media, as explained in U.S. Patent 5,423,892, variables concerning efficiency include: percent solidity of the media, and how compressed the media is within the construction involved; overall thickness or depth; and, fiber size.

For open cell foam media, generally the variables of interest with respect to efficiency are the thickness of the media, the cell density (or porosity), and the average cell size. For PTFE microporous membranes, or similar constructions, generally the principal variables of concern to efficiency are the extent of biaxial stretching in the formation of the membrane, resulting in an average pore size

between the fibrils. If the microporous membrane is laminated to, or otherwise positioned adjacent to a support material, as is typically the case, the support material (for example, felt or scrim) may also contribute to efficiency and restriction.

Air cleaner shape and structure are greatly factors concerning: (1) the manner in which the air is directed against and through the media; (2) the extent to which the mechanical equipment (housing shape, internal structures, duct size, etc.) on either side of the media affect or contribute to restriction; and, (3) the extent to which the air being filtered is preclassified by a precleaner, upstream of the media. With respect to such precleaner constructions, attention is directed to U.S. Patents 5,545,241 and 5,401,285, incorporated herein by reference. In the '241 patent, a cyclonic precleaner in the housing, is described at col. 4, lines 37-50. In the '285 patent, the precleaner is outside of the main air cleaner housing, as described at col. 6, lines 29-46.

Additional concerns with respect to air cleaner shape and structure include: size design for serviceability, including access by the service personnel and ease of removal and replacement of media; ease of assembly and mounting; and, seal design for filter elements positioned therein.

With many engine air cleaner arrangements currently in the market, at least one of two general types of sealing arrangements between the element and the housing are used. One of these is a radially sealing arrangement. A variety of configurations of radially sealing arrangements are known, including: (1) the form available under the Donaldson trademark RadialSeal® from Donaldson Company of Minneapolis, Minnesota, and generally as described and characterized in European Patent 0329659B1, incorporated herein by reference; (2) the type described by Mann and Hummel in German Patent 4,241,586, and the corresponding (English language) published South African document 93/09129 published May 8, 1994, incorporated herein by reference; and, (3) the type characterized by Fleetguard in U.S. Patent 5,556,440 at column 10, lines 53-67 and Fig. 7, incorporated herein by reference. In general, with radially sealing arrangements, a seal is formed as a result of forces directed radially around a tube to which the element is sealed.

Another common type of sealing arrangement is generally referred to as "axial". Axial systems are shown, for example, in U.S. Patents 3,078,650;

3,488,928; 4,647,373; and 5,562,746 each of which is incorporated herein by reference. In general, sealing forces for such arrangements are directed along the longitudinal axis of the cylindrical air filter element that result from compression of a gasket between an end surface of the air filter and a surface of a housing in which the air filter is positioned, with the seal oriented circumferentially around (or circumscribing) an air flow aperture or tube.

E. An Example of Applications of Principles Relating to Air cleaner Design--A Typical Cylindrical Vehicle Engine Air Filter

As indicated above, with many vehicle engine air filters, a preference has been developed for cylindrical air filter elements. Reasons for this vary including: use of established filter element manufacturing techniques; convenient housing design; familiarity with respect to servicing; ease of servicing; robustness, etc. With such cylindrical arrangements, in general, two flow patterns have been developed: a forward flow arrangement in which the flow, during filtering, is from an exterior of the cylindrical media through the media to an open interior; and, a reverse flow system in which air flow during filtering is from an open interior of the cylindrical construction, through the media, to a region exterior. In many instances, principles characterized herein can be applied in either situation.

Herein when reference is made to air filter elements, in some instances characterizations will be made with respect to relative positioning of media components or other components in the system. For convenience, reference is made with respect to "normal" air flow through the system, during normal or intended use, i.e. when the element is operably positioned in use. Thus a "most upstream" component, is the most upstream component within the system with respect to normal, filtering, air flow in use. If the arrangement is forward flow, this would typically be the outermost component. On the other hand, if the system were designed for reverse flow, this would typically be the innermost component, for cylindrical systems. In some instances, components will be described relative to one another, i.e. more upstream or more downstream from another component. When such a characterization is used, reference is meant to the relative positioning when

the element is operably positioned or installed (i.e. installed for use) and analogous positioning is meant, namely: generally more outwardly for forward flow arrangements; or, generally more inwardly for reverse flow arrangements.

For purposes of the present description of an example, a construction in which a forward flow arrangement is involved, will be assumed. (Of course similar principles would apply with reverse flow.) With a forward flow arrangement involving a cylindrical air filter, the open interior of the air filter is provided in air flow communication with an outlet duct, to the engine. The outlet duct operates as a clean air duct directing airflow from the clean air side of the media, i.e., the interior of the cylindrical air filter, through to the engine air intake manifold. Forward flow arrangements, using a radially sealing construction for the filter element, are described and shown, for example, in U.S. Patent, 5,423,892, especially with respect to the description concerning Fig. 2. A preferred profile for the radially sealing material, is shown in the '892 patent at Fig. 9.

In general, the duct size for the outlet tube is a major factor in determining or setting element size. The duct size will generally be chosen by the engineer designing the system based upon specifications provided by the original equipment manufacturer or engine manufacturer, and the amount of air flow restriction acceptable. For many engines, especially for use in over-the-highway trucks and similar equipment, the design will be for a flow velocity in the duct, during normal operation, on the order of about 4,000 or 5,000 feet per minute (fpm). In general, air flow velocity is used as a factor to determine appropriate duct size. More specifically, the engine air take inlet flow for typical or preferred operation, when divided by the velocity, provides for a nominal cross-sectional size of the duct. Since circular ducts are generally preferred, the cross-sectional size can be related to the size or diameter of the duct (internal) as a function of the area of a circle (the inside cross-sectional area of a round tube). As indicated below in some instances the engineer adds to the i.d. of the outlet tube, where the element mounts, sufficient diameter to accommodate a safety filter or safety element.

For a variety of truck engines, air flow velocities on the order of about 2000 ft/min. to 7000 ft/min. are typical, with 4,000 - 5,000 ft/min being quite

common. As a general matter for a truck, clean air duct diameters on the order of about 1.38 inches to 10 inches, in various increments, are typically used and stocked.

A variety of schematic systems have been developed to facilitate determination of appropriate duct size for an engine. A typical example is provided in Fig. 9. Referring to Fig. 9, a graph reflecting, along one direction, duct restriction, in inches of H_2O (0.01-1.0), and flow demand (10-10,000 cfm) along the other; and internal lines reflecting flow velocity (2000 ft/min. up to 7000 ft/min) and duct size (from 1.38 inches to 10.00 inches) is shown. An example of how to use the graph for a 600 cfm system and an acceptable restriction of 0.06 inches H_2O is shown by the dotted lines. The intersection between the dotted 600 cfm system line and the 0.06 inch H_2O restriction dotted line is at a duct size of 5 inches.

Using relationships as reflected in Fig. 9, engineers generally have developed standards for duct size and air intake systems.

Since, for many typical forward flow arrangements, the duct inserts into, or fits, the interior of the cylindrical air filter, it follows that typically the internal diameter of the cylindrical air filter should be at least as large as the duct size. When a radially sealing arrangement of the type characterized in Donaldson European Patent 0329659B1 is involved, typically a filter inner liner internal diameter on the order of about 8% to 15% larger than the outlet duct will be preferred. This typically converts to about 0.25 to 0.75 inches larger. When an axial system of the type characterized in U.S. Patent 5,562,746 is involved, typically an inlet diameter on the order of about 2% to 5% larger than the outlet duct will be preferred; this usually converts to 0.1 to 0.3 inches larger.

When the air cleaner is designed for off-road use, in some instances, the portion of the outlet tube which projects into the primary element has an increased diameter, relative to the remainder of the outlet tube feeding from the air cleaner to the intake duct of the engine, in order to accommodate the positioning of the safety filter element. This diameter increase, when used, is typically 1.0-3.5 inches greater in diameter, than a typical on-road element for a similar rated engine flow. When such is the case, the internal diameter of the primary filter element is increased accordingly, to accommodate for the space of the safety element. A typical manner in which this is accomplished, is described in Section L below.

From the above, it can be seen that in general the internal diameter of the cylindrical air cleaner, for a forward flow arrangement, is greatly a function of the specification for the engine and the selected duct size for desirable airflow without unacceptable restriction. (A similar statement would be true for a reverse flow, only it would relate to the air inlet duct size.) In some instances, it is also a function of the size of a safety element that is to be positioned inside of the primary element, in use. In any event, once the primary element internal diameter is set or selected, the engineer begins to work with principles for otherwise defining the air filter construction. If one continues to assume a cylindrical air filter design, among the factors facing the engineer are: (1) media choice; (2) cylindrical thickness; and, (3) cylindrical length. These latter two factors can be characterized together as media volume.

The most common type of air filter media in use today, especially in vehicles, on and off road, is pleated filter media, typically paper or cellulose media, in some instances with synthetic fibers. Indeed, in some applications pleated synthetic media has been used. For purposes of this section of the presentation, we will consider a typical, conventional, pleated paper filter design, which is an extremely common design today.

In general, the engineer will have selected a cellulose fiber media appropriate for the desired initial filter efficiency and overall filter performance. Typically, as indicated above, the permeability selected will be somewhere in the range of about 10-25 fpm. A typical one used by Donaldson Company Inc. is one having a permeability of about 13 fpm.

For many conventional designs, the media will be arranged in a cylindrical, pleated, pattern, such as that shown, for example, in U.S. Patents 5,112,372 and 5,547,480, incorporated herein by reference. With many conventional systems, this pleated media is positioned between an inner liner and an outer liner, as shown in the 5,547,480 patent at Fig. 2, col. 2, lines 61-67.

In typical designs, the size of the pleated cylinder, both thickness and length, will be selected based upon the characteristics of the pleated media, and the efficiency and lifetime desired. In general, for any given system the higher the barrier media surface area presented to the incoming air, the lower will be the "face

velocity" of the media. Face velocity is generally reported or characterized in feet per minute, and is the volume of airflow (rated), in cubic feet per minute, divided by the surface area of media encountered by the airflow during filtering. For typical vehicles or equipment using pleated cellulose media (medium duty), the arrangement is designed for a pleated media face velocity of no greater than about 15 fpm, typically about 10-15 fpm. In those instances in which an adjustment for an extended life filter is desired (heavy duty), generally the size is selected so that the pleated media face velocity is on the order of about 5-10 fpm or about 0.5 times the medium duty face velocity. This latter follows since the higher the face velocity directed at pleated media, the larger will be the amount of contaminant directed against any given area, and the more rapidly that area will occlude or blind off, (with concomitant restriction increase). Thus, for longer life, with barrier filters, the engineer designs the element for higher available surface area and lower face velocity. Of course the relationship between size and face velocity is proportional. That is, to cut the face velocity in half, double the media surface area. This can increase lifetime, however, by more than 2-3 times. (In many instances for a given application, an engineer will simply double the media volume for the heavy duty element, relative to the medium duty.)

In addition to the restriction or lifetime concerns presented in the previous sentence, another factor of concern with respect to design of face velocity in a pleated media system, is efficiency. The higher the face velocity, the more kinetic energy the particles will possess when they encounter the media. As a result, the more likely will be the possibility that the particles pass through the barrier media, rather than being stopped at the surface, especially initially before filter cake develops. In addition, the higher the face velocity, the higher will be the amount of contaminant directed against any given unit area within a fixed period of time. Thus, if all other variables are fixed, and the design of a barrier filter is modified to increase face velocity, initial efficiency decreases, average efficiency decreases and lifetime shortens. As a result, with pleated cellulose or similar surface or barrier media arrangements, sizes appropriate for face velocities of at 15 fpm or below are the norm for medium or heavy duty elements.

If one now considers the space between the inner and outer liner to be the available volume for the media, and a factor with respect to configuration and size to be the desired average face velocity during use, another step in the design approach becomes apparent. By modifying the pleat depth and the pleat length, the engineer can adjust the size and, thus, the average face velocity. With respect to pleat depth, however, for typical desirable cellulose fiber pleated media, an overall pleat depth maximum of about three or four inches is typical, since when a pleat depth greater than about this is involved, pleat structural integrity lowers and manufacturing problems can occur.

Typically, the pleat population is controlled by the thickness of the media and the extent to which the pleats need to fan out or space out for efficient filter cake build-up and airflow. For typical truck filters, a pleat population density on the order of about 9-14 pleats per inch, along the i.d., are usually maximum. (Pleat density is usually reported as the number of pleats per unit length along the internal diameter, i.d., of a cylindrical pattern.)

From the above, one can see that there are limits to the extent to which the design engineer of the air cleaner can utilize pleat population and pleat depth to modify and reduce face velocity. As a result, in many instances another variable, i.e. pleat length, is applied. That is, for a pleated filter of given pleat depth and pleat spacing, pleat surface area can be readily doubled by doubling pleat or cylinder length.

Of course, at some point, a maximum size convenient for the air cleaner housing and positioning upon the vehicle or other equipment, becomes a limiting factor. In addition, for a variety of systems, overall weight, filter element expense, filter element disposal, ease of servicing, etc. also become key factors.

At this point, it is convenient to also consider the "approach velocity" for the filter element. In general, the approach velocity will be the velocity of air (at rated flow) seen by the most upstream geometric perimeter or surface of the air cleaner. For a forward flow element, having an outer liner, the approach velocity would be the air flow of the engine at rating, divided by the exposed outer porous liner cylindrical surface area (i.e. the portion not embedded in the end caps). In general, for a pleated paper air cleaner, the approach velocity would be substantially

higher than the media face velocity, since the overall upstream surface area of the media would be much higher than the outer surface area of the cylindrical outer liner. Typical cylindrical pleated paper air cleaners (medium duty) are designed with an approach velocity of about 230 fpm.

F. A Second Example of Principles Relating to Air cleaner Design-A Cylindrical Vehicle Engine Air Filter Using A Combination of Depth Media and Pleated Paper Media

Principles relating to air cleaners using combinations of depth media, with or without pleated paper media, are characterized in U.S. Patent 5,423,892, incorporated herein by reference. Also, many of the various arrangements characterized herein are various, specific, applications of these principles.

G. Certain Improved Filter Constructions with Respect to Initial Restriction and/or Overall Performance

In one approach to improving filter performance, in particular with respect to initial restriction, according to the present disclosure the internal diameter of the cylindrical filter is increased, and the overall thickness of the media pack, i.e., the distance between the inner and outer liners, is decreased. In addition, the material utilized in the media layers is selected, to obtain desirable performance with respect to efficiency, restriction and lifetime.

An example of such an improved filter element according to the present invention is illustrated in Fig. 1, in cross-section. The filter element of Fig. 1 is designed to fit on a standard outlet tube. That is, the arrangement was designed to retrofit a system in which a previous filter construction was used, with a smaller internal diameter for the media pack or inner liner. The arrangement is also designed to use a Donaldson Company radially sealing construction of the type as generally characterized in European Patent 0329659B1, incorporated herein by reference, except modified for the preferred profile shown in Fig. 1, although it could readily be modified to accommodate alternate sealing approaches. Dimensions for an example element according to Fig. 1, and other preferred specifications, are provided hereinbelow in Section J.

As can be seen from a review of Fig. 1, and upon evaluation of the specifications provided in Section J below, the arrangement of Fig. 1 has a larger internal diameter by comparison to certain prior arrangements which would have a similar outer diameter. Referring to Fig. 1, reference number 1 indicates the filter element. The filter element 1 generally includes an outer liner 2 and an inner liner 3. A media construction 4 is positioned between the outer liner 2 and inner liner 3. A variety of materials can be utilized for the outer and inner liners (2, 3) including expanded metal, perforated metal and plastic liners, as examples. In general, the outer and inner liners (2, 3) should: (a) be selected of materials appropriately perforated or otherwise made porous so as not to substantially interfere with airflow through the arrangement; and (b) be of appropriate structural rigidity and strength to contain the media construction and provide the arrangement with sufficient axial strength for the use intended and to protect the media construction from damage. Typical liners have an open area of at least 50%, often 60% or more. Galvanized metal or plastic arrangements are typically preferred. Herein the combination of the outer liner 2, inner liner 3 and media construction 4 will sometimes be referred to as the media pack 5.

The filter element 1, depicted in Fig. 1, includes first and second opposite end caps 6 and 7. In the arrangement shown, the media pack 5 is embedded in, and extends between, the end caps 6 and 7. The particular preferred arrangement shown utilizes end caps 6 and 7 formed from a soft, compressible elastomer with the liners 2,3 and the media construction 4 embedded therein. In some arrangements, harder material can be used as the end caps, with the media and liners secured to the end caps by potting material such as an adhesive, for example, a plastisol adhesive.

While a variety of materials can be utilized to form the end caps 6, 7, for the preferred arrangement shown, as indicated above, foamed polyurethane material is used. Such materials are characterized for example in U.S. Patent 5,669,949 at column 9, lines 11-59, incorporated herein by reference and would preferably comprise a soft polyurethane foam having an "as molded" density of 14-22 lbs./ft^3 and which exhibits a softness such that a 25% deflection requires about a 10 psi pressure.

Still referring to Fig. 1, it is noted that end cap 7 is a "closed" end cap. That is, end cap 7 includes no airflow apertures therein, so, in general, air is prevented from flowing through end 8 from an exterior of the filter element 1 to interior volume 10.

In contrast, end cap 6 is an"open" end cap, having central aperture 12 therein. In use, filter element 1 is secured within an air cleaner with aperture 12 circumscribing an air flow tube or aperture. As a result of the use of appropriate sealing (via a variety of possible manners), for designs such as the one shown in Fig. 1, airflow is inhibited from reaching aperture 12, (and thus from being directed into an outlet tube for direction to an engine air intake) without filtering flow through media pack 5. For the arrangement shown, aperture 12 is defined by Donaldson radially sealing structure 14. As generally characterized in European Patent 0329659B1, the sealing structure 14 comprises soft compressible foamed polyurethane positioned as shown at region 15. Region 15, defining aperture 12, has a stepped cross-sectional configuration of decreasing diameter between points 16 and 17, to achieve desirable sealing. Preferred specifications for the profile of particular arrangement shown in Fig. 1 are as follows: a polyurethane foam material having a plurality of (preferably at least three) progressively larger steps configured to interface with the outlet tube and provide a fluid-tight seal. The larger a step, the smaller the resulting internal diameter is in the corresponding portion of the end cap, and the larger will be the compression when the element is mounted on an air flow tube.

In general, for a properly functioning Donaldson type radially sealing structure, the material in region 15 needs to be substantially compressed when the element is mounted on an outlet tube. In many preferred constructions, it is compressed between about 15% and 40% (often about 20-33%) of its thickness, in the thickest portion 18, to provide for a strong robust seal yet still be one that can result from hand installation of the element with forces on the order of 80 lbs or less, preferably 75 lbs or less, and generally 50-70 lbs. In the past, for many preferred Donaldson radially sealing products, the compression has been provided between the inner liner 3 and an outlet tube (not shown in Fig. 1). A specific example of an

arrangement using such a seal is shown in European Patent 0329659B1 and herein in Fig. 5 discussed below.

Referring again to the arrangement of Fig. 1, the inner liner 3 is not appropriately positioned to operate alone as a desirable backstop and to facilitate the appropriate amount of compression. In particular, the inner liner 3 has been changed from its "normal" location indicated at phantom line 20, for prior elements, to the position shown, a distance of greater than 0.25 inch (indeed typically greater than about 0.5 inch and preferably about 1 inch) further away from region 15. This increase in distance is too great to allow for the formation of an appropriately robust seal. This is because even if the space between the inner liner 3 and the region 15 were filled with compressible material, the distance would be so great that the amount of compression, when pushed over a conventional outlet tube, would not be sufficient for a desirable seal.

In order to incorporate a Donaldson radially sealing arrangement of the type characterized in European Patent 0329659B1, or as shown herein in Fig. 5, in the arrangement of Fig. 1, an additional inner filter liner, insert or support has been provided. The inner filter liner or support, which can be viewed as, at least in part, comprising an adapter or adapter ring construction, is indicated generally at 23. The inner filter liner or support is illustrated generally in Figs. 1 and 2.

Referring to Fig. 2, the inner filter support 23 comprises a generally circular structure and includes thereon an inner cylindrical wall 25, and a projecting extension wall section 35, extending from and circumscribing the wall 25. Wall section 35 generally defines a circular outer perimeter portion or perimeter area 35a.

In general, the inner cylindrical wall 25 is positioned behind region 15 appropriately to provide for the desired amount of compression of region 15, during sealing engagement with an air flow tube. This will be understood by reference to Fig. 1. The positioning of the inner cylindrical wall 25 will be selected such that the total amount of compression of region 15, during engagement with an outlet tube, will be such as to provide for a compression on the order of about 15% to 50%, usually 20-33%, typically over a distance of at least about 4 mm (millimeters) and generally about 5 mm to 12 mm, during desirable sealing. In typical arrangements, the inner cylindrical wall 25 will extend generally parallel to a

central longitudinal axis 30 of the cylindrical element 1, Fig. 1. However, such is not required. The cylindrical wall 25 could have, for example, a somewhat truncated conical shape in some embodiments. This could be used, for example, to modify the force of sealing (sealing force) in different portions of the radial seal or to modify flow properties of the urethane, during molding.

In some applications, the inner cylindrical wall 25 will have a smooth, non-porous, continuous inner surface 32. This will, in some instances, be preferred for ease of manufacture, assembly and convenient preferred operation. However, again, modification involving non-smooth surfaces or even porous surfaces, can be used in connection with the principles of the present invention. In general, the length of inner surface 32, between points 33 and 34, Fig. 1, will typically be at least 0.5 in. and usually 0.75 to 1.25 in. for vehicle filters. In Fig. 2A, an optional "toothed" pattern in the surface 32 is shown. Generally 10 to 14 evenly, radially, spaced notches 43, of 0.1-0.4 in. by 0.1-0.4 in. will be enough to allow a desired flow to the polymer during cure. The notched pattern allows the urethane to flow "through" surface 32, to enhance bonding.

Fig. 2A is a schematic illustration of inner filter support 23. As a schematic illustration, the circular configuration of the side of cylindrical wall 25 is not illustrated as viewable through notches 43. It should be understood that in an actual filter support 23, depending upon the angle of orientation, portions of cylindrical wall 25 would likely be viewable through notches 43.

Preferred inner filter supports 23, according to the present invention, will generally comprise integral molded constructions of a relatively rigid plastic, for example molded high impact polystyrene. When such a material is used, preferred thicknesses for the inner cylindrical wall 25 will be on the order of about 0.05 to 0.1 in.

Still referring to Figs. 1 and 2, the inner filter support 23 includes extension wall section 35, from which wall 23 depends. An optional aperture pattern for wall 35 is shown in Fig. 2B. This pattern allows for flow of polymer therethrough, during cure, to facilitate attachment. Typically 10 to 26 evenly, radially, spaced apertures 42 of 0.3 to 0.5 in. diameter size will be enough. (In general, apertures 42 and notches 43 can be characterized as free rise apertures, since

they allow for flow or rise of polymer through portions of support 23 during molding of end cap 6.)

Referring again to Figs. 1 and 2, the support 23 further includes feet 36 extending above and laterally from section 35a. Feet 36 are supported by legs 36a. In general, feet 36 include tips 37 oriented to be positioned over the filter pack 4, Fig. 1, in use, with legs 36a depending from feet 36 to perimeter area 35a. Legs 36a are preferably sized to compress against a portion 39 of inner liner 3 during assembly. In general, what would be preferred is that legs 36a be configured such that, during assembly, support 23 can be pressed into end 41 of media pack 5 and be adequately secured in place, for media pack 5 to be inverted with the support 23 retained thereon by interference or friction fit caused by legs 36a. As a result, the assembly can be lowered into a mold for application of the endcap material 6 without inadvertent separation of the support 23 from the remainder of the media pack 5. In the resulting element, feet 36 are preferably at least partially embedded in, or positioned underneath, the end cap material.

In general, the size and shape of extension 35 should be appropriate to position inner surface 25 the desired distance from liner 3 and appropriately for backing up the radial seal of section 15. Preferred dimensions for one arrangement are provided hereinbelow. Preferably 5 to 12 evenly (radially) spaced feet 36 are used. (As a result of the design of spacer or support 23, the compression at section 15 is caused by both the inner liner 3 and the support 23 pushing against the polymer.

Referring to Fig. 2, in phantom lines optional gussets or struts 40 are indicated, to strengthen wall 25. With molded filter support 23, the struts 40 can be included via conventional molding techniques. It is noted that the struts are optional, and in many instances may not be required or desired. If struts 40 are used, it is anticipated that at least four would preferably be used, also preferably evenly (radially) spaced.

In some conventional molding techniques employed herein, filter support 23 may be injection molded. As such, a negative or cavity forming the filter support 23 is formed in a shell construction, typically with slanted walls or draft angles. A molten plastic material is injected into the vacant cavity and allowed to

cool. After cooling, the shell is opened and the molded filter support 23 is removed from the cavity. Draft angles on the structure allow for easier ejection from the mold. Struts can be added by modifying the negative or cavity to allow for the strut structure extending between section 35 and wall 25.

Still referring to Fig. 1, the preferred filter element 1 depicted includes exterior axial projection arrangement 49 on exterior surface 50 of end cap 6. A similar companion arrangement 51 is depicted on an exterior surface 52 of end cap 7. Projection arrangements 49 and 51 help ensure a snug fit for element 1 between opposite end walls of an associated air cleaner. Similar constructions were described in EP 0329659 at column 5, lines 7-10. Except for having a length (relief or profile) appropriate for this, the size and shape of arrangements 49, 51 are generally not of great significance, with respect to performance. It is noted that as a result of the presence of the radial seal involving region 15, fluid tight seals between end walls of an associated housing, and outer surfaces 50 and 52 are not required. That is, projections 49 and 51 need not comprise seal rings (although they can be made as seal rings). The projection arrangements 49 and 51, as a result of the snug arrangement, will help to inhibit undesirable levels of bouncing movement or vibrational movement of element 1 during use, especially as the element 1 gains in weight as a result of contaminant load thereon.

For the particular embodiment illustrated in Fig. 1, as indicated above, the filter element has a relatively thin media pack on the order of 2.25 inches or less, preferably no more than 1.75 inches, typically 1.0-1.75 inches, most preferably about 1.5 inches, due in part to the relatively large element i.d. However, although the initial restriction is reduced and the media pack is relatively thin, the outside diameter will typically be such as to provide an average approach velocity of about the same as that for a typical pleated paper arrangement used in a similar environment. That approach velocity is about 230 fpm or less (medium duty).

A schematic cross section of a useable media pack 5 for arrangements analogous to those shown in Fig. 1 is provided in Fig. 3. In Fig. 3 a fragmentary cross sectional view of the media pack 5 taken generally along line 3-3, Fig. 1, is presented. The depiction in Fig. 3 is not intended to be precise with respect to proportion, but rather should be viewed as schematic.

Referring to Fig. 3, the media pack 5 (or media construction 4) includes a plurality of (three in the specific figure) general media regions indicated at 55, 56 and 57, between outer liner 2 and inner liner 3. Region 56 is a region of pleated barrier media. Region 55 is a region of depth media positioned upstream from the pleated barrier media 56. Region 57 is a region of depth media positioned downstream from the pleated barrier media 56. It is noted that upstream region 55 comprises multiple layers, in the preferred arrangement shown, three layers 58, 59, and 60, with region 58 the most upstream, region 59 the next, and region 60 the next and most downstream (in region 55). Preferred media formulations for media pack 5 (or media construction 4) are characterized hereinbelow, in section J. It is noted that an alternate number of layers to the three shown in region 55 can be used, in some constructions.

When a media pack 5 is made relatively thin, i.e., < 2.25 inches, typically 1.0-1.75 inches, (and in many instances less than 1.6 inches) it should be recognized that some loss of efficiency will necessarily result if other variables are held constant, since less media will be present in the arrangement. To accommodate this, modifications in the media construction to achieve a desirable efficiency have been undertaken.

As this disclosure in section J below indicates, the preferred media pack used as a media pack 5 in the filter element 1, does not use an oiled cellulose fiber media. Rather dry media is used. Also, the pleated media is made from a relatively high perm barrier material (prior to application of any oil or fine fiber thereto), having a permeability of greater than 25 fpm, typically greater than 35 fpm and preferably at least about 45 fpm, typically 50 to 60 fpm.

In general, as explained in U.S. Patent 5,423,892, oil in media is of assistance with respect to very small particles. However, oil is preferably avoided. In order to avoid undesirable levels of loss of efficiency due to the high perm pleated barrier media, used in the arrangement 1, on one or more surfaces of the pleated paper media 56 is preferably provided with fine fiber applied thereto. Typically, and preferably the fine fiber application will be to the upstream side of the barrier media, but such is not required. In general, fibers of about 5 micron or less average fiber diameter, for example sub-micron, would be preferred for this application. The

amount of fine fiber application will depend upon the overall efficiency desired by the engineer for the pleated media portion of the construction involved. In a particular preferred application for filter element 1, namely the one specified in section J, sufficient fine fiber media should be applied to provide for achievement of overall desired efficiency in the media pack. As a result, a pleated media having a permeability, after fine fiber application, on the order of about 20 fpm to 35 fpm (typically 25 fpm to 30 fpm) will be useful, in many applications.

A variety of methods can be utilized for application of the fine fiber to the media. Some such approaches are characterized, for example, in U.S. Patent 5,423,892, column 32, at lines 48-60. More specifically, such methods are described in U.S. Patent Nos. 3,878,014; 3,676,242; 3,841,953; and 3,849,241, incorporated herein by reference. Another alternative is a trade secret approach comprising a fine polymeric fiber web positioned over conventional media, practiced under trade secret by Donaldson Company under the designation ULTRA-WEB®. However, there is no particular preference with respect to the operation of the arrangement 1 for: a particular material from which the fine fibers are made; a particular method used to apply the fine fibers; or, in many instances, a particular fine fiber size, as long as fibers of about 5 micron or less and in some instances submicron are involved. In general, preferences will be defined, for any given situation, based upon whether overall desirable restriction, initial restriction, initial efficiency and overall efficiency for the resulting media pack 5 are obtained. Of course, these preferences somewhat depend upon the environment in which the element is to be used and the type of particulates likely to be encountered, as well as specifications of the engine or vehicle manufacturer.

Again, for the filter element shown in Fig. 3, a region 57 of non-woven fibrous material is positioned downstream, or along the interior of, pleated media 56. This region 57 may be of the type characterized in U.S. Patent 5,423,892 with respect to Figs. 15 and 16 at reference numeral 323. As can be seen from this specification in sections I and J, a variety of materials can be chosen. The particular selection will depend upon the overall restriction, initial restriction, overall efficiency and initial efficiency desired. In general, the various materials indicated

in sections I and J will be usable, with the final selection depending upon the effect on the performance parameters desired, for any given situation or application.

Still referring to Fig. 3, upstream from pleated media 56 is positioned a depth media volume 55. For the preferred arrangement depicted, the depth media volume 55 extends from the outer tips 56a of the pleated media 56 to abutting relationship with the outer liner 2. For typical arrangements of the type characterized in Fig. 4, this distance will typically be about 0.5 inches to 1.5 inches, usually about 0.5 inches to 1.0 inches; for specific embodiment of the type shown in Fig. 1, for example, it would be about 0.75 inches.

For the particular preferred arrangement of the specification in Section J, the depth media in each of regions 58, 59 and 60 comprises fibrous depth media, although other types of depth media can be used. Preferably the regions 58, 59 and 60 are arranged such that, in general, an increase in filter efficiency is observed in comparing filter efficiency in a portion of region 58 immediately adjacent outer liner 2 to a portion of region 60 immediately adjacent pleated media 56. As explained in sections I and J below, the gradient can be continued throughout depth media volume 55, or it can be stepped. Typically and preferably it will be stepped. Further, a gradient can be provided between any two adjacent regions, or, in some instances, two or more adjacent and substantially similar regions can be used, depending upon the particular construction preferred.

In order to accomplish a desirable efficiency and lifetime, with a relatively thin filter pack of the type characterized for use in Fig. 1, it was determined to be desirable, for at least some preferred applications, that the media type and thickness used in each of the various regions be selected to provide a more even distribution of particulates, during load, than were characterized for certain of the most preferred embodiments of U.S. Patent 5,423, 892. For example, it was determined that a preferred material for region 58 would be one selected to provide for: (a) a high particulate load during use, within region 58, on the order of at least 35 percent and typically about 40-70 percent, by weight, of total load within filter element 1 during use or when tested according to the procedure of SAE J726; and, (b) which will provide a total load in region 58 of about 45 to 70 percent (based on weight) with respect to total load within the depth media of depth media volume 55

during typical operational use, or when tested according to the procedure of SAE J726.

Thus, extremely high efficiencies or load (greater than 80% of total element load) in the outermost region of depth media volume 55, i.e., in region 58, are generally less preferred. This is because when high efficiencies or load are used in this region, good use of the available depth media volume 55 is not necessarily made, filter lifetime may be shortened, and premature occlusion or restriction increase will likely result.

In general, as indicated by the descriptions in sections I and J below, and the general teachings of U.S. Patent 5,423,892, the outermost region 58 is selected to receive a relatively high load of 1 to 10 micron particles therein. Thus, region 58 will tend to classify the contaminant with respect to the material that reaches inner layers, including regions 59, 60 and pleated media 56. Of course, it is recognized that relatively high kinetic energy particles will tend to pass region 58, especially initially before particulate load within region 58 achieves a significant level. However, especially with designs having an overall approach velocity of about 200-500 fpm, a high amount of particulate load involving relatively small particles will generally occur within region 58. Indeed, it has been found that even a relatively high amount of carbon particle load will occur in the region 58. In fact, in some instances, 40-60% of the total carbon load (within the whole filter element) occurs at this location. In general, the amount of load of such particles can be controlled by the fiber size selected for region 58, along with the depth and overall percent solidity. (It is noted that in some instances, small carbon particles will agglomerate, in region 58, into larger agglomerates. These agglomerates may remain in region 58 or be "knocked off" to move into more downstream media.)

For the preferred arrangements characterized in sections I and J below, and a preferred arrangement according to the construction of Figs. 1 and 3, the middle regions 59 and 60 have smaller average fiber diameters (or are otherwise modified) than the media in region 58, in order to increase efficiency for trapping of particles which pass region 58. Of course, this means that the media of regions 59 and 60 is more susceptible to occlusion than the media in region 58, if tested in side-by-side comparison. However, as a result of having region 58 upstream of regions

59 and 60, region 58 will operate as an upstream filter to classify the material, allowing a different population of material to pass into regions 59 and 60 than the material which region 58 sees, during filter operation. Thus, a desired level of efficiency, preferred initial restriction, and preferred operating efficiency and operating restriction can be obtained, and adjusted, by choice of media in these various regions.

H. Development of High Approach Velocity or Low Media Volume Filter Designs

Certain principles described herein can be utilized in the development of unique, low media volume arrangements or, as a result in some instances, relatively high approach velocity arrangements. In general, a “high” approach velocity system or "low" media volume arrangement is an arrangement which is designed to have a higher approach velocity or lower media volume than would be typical for previous (typically pleated paper) designs in a similar context.

In general, designs of high approach velocity or low media volume filter arrangements according to the principles of this section, can be generally subdivided into three types: elements for light duty applications; elements for medium duty applications; and, elements for heavy duty applications. With conventional pleated paper arrangements, light duty arrangements are generally designed with a face velocity of 15-20 fpm, medium duty with a face velocity from about 10-15 fpm and heavy duty with a face velocity of about 5-10 fpm.

In general, an element for a high approach velocity medium duty application, utilizing the principles characterized herein, is one which has been designed by the engineer to have a face velocity or approach velocity of no less than about 380 feet per minute, preferably no less than about 420 feet per minute and most preferably no less than about 450 feet per minute (and typically at least about 450 feet per minute to about 460 feet per minute or more) in the application involved.

Consider the design of a cylindrical filter element utilizing preferred media pack designs according to the present invention and configured for use as a

medium duty element, in some selected engine situation. A high approach velocity element, for such a situation, would generally be one designed as follows. The engineer would determine the rated air flow demand of the engine, for example, at least 500 cubic feet per minute, 900 cfm, 1000 cfm, 1200 cfm, 1400 cfm, etc. provided by the engine or vehicle manufacturer. From this information, the engineer would know the preferred internal duct diameter, for desired restriction, as discussed above. (This would typically be determined by the engineer based on specifications from engine manufacturer or vehicle manufacturer.) This would set a lower limit on the internal diameter of the element. Of course, the engineer would need to accommodate any additional i.d. greater than the duct size needed for sealing configurations, safety elements, etc. The engineer would use as the surface area for the outer cylindrical liner, or outer liner of another configuration, whatever area would provide for an overall approach velocity of no less than about 380 feet per minute, preferably no less than about 420 feet per minute, most preferably no less than about 450 feet per minute, and typically about 450 feet per minute to about 460 feet per minute or more. Preferably, the outer liner size and configuration would also be selected such that the overall media pack (or media construction) thickness would be in the range of about 1.0 inch to 2.5 inches, typically < 2.25 inches, preferably about 1.0 inch to 1.75 inches.

The engineer would then "fill in" the available media volume with preferred media packs as generally characterized in Sections I-K herein.

A similar approach to a medium duty element can be conducted by the engineer, using a calculation based upon media volume, rather than approach velocity. In general, the engineer will calculate the media volume for the application that would be needed for a pleated paper element. The engineer would then downsize that volume to no more than about 60% of the figure, preferably about 45-55% of the figure, and fill the volume with a media pack as described herein. Typically and preferably the volume selected is set to be no greater (in cubic feet) than the flow demand for the engine involved, in cubic feet per minute, divided by a flow index of 2,737 min.$^{-1}$; preferably it is set to be no greater than the flow demand for the engine of concern, in cubic feet per minute, divided by a flow index of 2,985 min.$^{-1}$; and most preferably the volume is no greater than the flow of demand of the

engine in cubic feet per minute divided by a flow index of 3,100 min.$^{-1}$. In typical preferred applications, the overall media volume is between about the flow volume for the engine of concern (in cfm) divided by a flow index of 3,100 min.$^{-1}$ and the value obtained by dividing the rated flow in cfm by a flow index of 3,285 min.$^{-1}$, or it is smaller.

Having calculated the desirable flow volume for the medium duty element, and knowing the internal diameter limitations due to the outlet duct sizes, the engineer can now design the media volume to be filled with the preferred media pack characterized herein, for the application. Again, in typical preferred applications the media volume should be designed to be no more than about 2.5 inches thick, preferably within no more than 2.25 inches thick, and typically the range of about 1.0 inch to 1.75 inches thick, most preferably about 1.1 inches to 1.6 inches thick.

For a heavy duty applications, typically relatively high rated engine demands will be involved, usually 1,000 cubic feet per minute or more.

Similar to the section immediately above, the engineer can base the design on overall media volume. In such a situation, the engineer should calculate the preferred media volume as follows:

The engineer would determine the media volume for a pleated paper element for a similar application, heavy duty. The engineer would downsize this volume to a value of no more than 60% of the figure, typically 45-55% of the figure. The engineer would then fill the volume with a preferred media pack, as characterized.

Typically, for heavy duty applications, the preferred media volume (in cubic feet) is no more than the rated engine flow demand in cubic feet per minute divided by 1,369 min.$^{-1}$; more preferably, it is no more than the engine demand in cubic feet per minute divided by 1,493 min.$^{-1}$; and, most preferably, it is no more than the rated engine demand in cubic feet per minute divided by 1,550 min.$^{-1}$; In some typical preferred applications, it will be about, or be less than, the range defined by the engine air flow demand divided by 1,550 min.$^{-1}$ and 1,643 min.$^{-1}$.

Most preferably, for some of the heavy duty applications, media packs of no more than 2.5 inches, and preferably less than 2.25 inches, typically on

the order of 1.0 inch to 2.0 inches in thickness in many instances, preferably about 1.1 inches to 1.75 inches in thickness, will be preferred. The preferred media pack constructions will be generally as characterized in Sections I-K below.

For light duty applications, similar principles for determining immediate volume within acceptable limits of approach velocity can be used. More specifically, the engineer will establish the pleated media volume for a standard pleated media element for the same application. This will typically be about 35% of the volume that would be appropriate for a medium duty element in the same application. In general, the engineer will develop the preferred element according to the present invention with an overall media volume of no more than about 60% of the typical light duty pleated element in volume, preferably about 45-55% of the standard pleated media volume.

I. Preferred Media For Use In Arrangements According to the Present Invention

In general, arrangements according to the present invention can be constructed utilizing materials corresponding generally to those characterized in U.S. Patent 5,423,892, incorporated herein by reference. The types of media components that may be utilized in arrangements according to the present invention can be generally categorized as falling into one of five categories:

1. high load, generally low solidity depth media;
2. intermediate depth media;
3. relatively high efficiency depth media;
4. pleated barrier media; and
5. depth media for use downstream of pleated barrier media (optional).

It is not necessarily the case that each and every application of techniques according to the present invention will involve media of each of the above categories. This will be understood from further detail below. Before particular uses and choices, and preferred arrangements, are characterized, the general types of media useable under the categories characterized above will be described. In general, when the engineer selects materials for the media construction, it will be designed from the downstream side toward the upstream.

1. The relatively high load high porosity (low solidity) depth media.

This type of media will generally be used, if at all, in constructions according to the present invention in the most upstream regions. The purpose of this type of media is to trap and load relatively large amounts of particles, without undo increases in restriction. That is, a purpose of such media when used is to allow for relatively high load in somewhat dusty environments, while still allowing for an extended lifetime of the resulting element. This material, when used, will help to classify the material which reaches inner layers.

The type of materials that will generally be trapped within such media are: particles which are sufficiently large that they are likely to encounter the fibers as the air passes through the media layer but which possess sufficiently low kinetic energy that they are likely to be trapped rather than bounce through the media. The precise classification of materials trapped within this media, when used, will depend, of course, upon the environment of use. In general, when used in an over-the-highway truck type situation, such media will generally trap a great deal of the contaminant from submicron carbon particle size up to about 10 microns or so.

In general, media that is preferred for this type of arrangement is a fibrous depth media in which the fibers have sufficient size and strength so that the open porous structure is maintained. Generally, media having an average fiber size, both on a weight average basis and on a length average basis, of at least about 20 microns, generally greater than 24 microns and typically 26 microns or larger will be preferred for this media. Mixtures of fibers, of different diameters, providing for average fiber sizes as indicated, are useable. In general, the preferred materials will

comprise polyester fibers, although in most applications the particular material utilized will not be critical.

In some instances, it may be desirable to provide the fibers with a sizing or similar material to facilitate rigidity and inhibition of collapse, under load, or to effect load or efficiency. Also, in some instances, it may be desirable to secure the media to the most upstream liner or similar structure, in order to inhibit collapse. This latter can be accomplished, for example, through the use of adhesives or similar attachment mechanisms. In U.S. Patent 5,423,892, this is described for example at column 13, line 65 - column 14, line 9.

In general, a variety of commercially available media can be used as this high loft type media. For example, commercial materials can be obtained from Cumulus Fibers, Inc., of Charlotte, North Carolina, or Fiber Bond Corp. of Michigan City, Indiana.

In general, the media will be preferred if it has a percent solidity, free state, of no greater than about 3% and preferably no greater than about 2% and typically somewhat lower. Such materials are readily available from the sources identified. By "free state" in this context, reference is meant to the percent solidity as the material is obtained from the supplier, and prior to any compression for installation in a filter element.

Herein, in some instances reference will be made to the percent solidity of the fibrous depth material "in the construction". By this characterization, and similar characterizations, reference is meant to the percent solidity as the material is found within the overall filter element. This percent solidity is generally a bit higher than the free state solidity, since in typical applications of the media will have been compressed somewhat when it is installed in a filter pack. Typically and preferably, when media of the type characterized in this section is utilized in a filter element, the amount of compression applied to the media will still be such that the percent solidity of the media, within the construction, is generally less than 3% and typically and preferably less than 2%. Most preferably, it is arranged so that within the construction it will have an average percent solidity within the range of 0.8% - 1.9%.

It will be observed from the characterizations of preferred media pack constructions hereinbelow, that media of the type characterized in this section be obtained from a media supplier in rolls or mats with the material having a free state thickness of about 0.30 to 0.75 inch. Typically, about 0.5 inch thick media, free state, will be preferred. This is convenient for creating arrangements as characterized hereinbelow. If thicker beds of this media are desired within the overall filter construction, more than one wrap or layer can be applied within the structure. Typically, the material will be compressed within the construction to form 1 or more layers, each of which is about 0.25 - 0.45 inches thick (average).

Herein in some instances, references will be made to wraps or rolls of the media around a cylindrical construction. When such is the case, the portion of transition, where the roll or layer overlaps itself, is not especially distinguished or differentiated. Such an arrangement, where in a single continuous material has been rolled around a construction twice, will generally be considered approximately equivalent to a construction in which two separate layers of the same material, each resulting from a single roll or wrap, are concentrically positioned.

In some instances, it may be desirable to utilize, as the depth media of the type characterized in this section, depth media which has a relatively high loft, i.e. a very low percent solidity, but which comprises a mixture of relatively large fibers, for example 26 microns average diameter or larger, with substantially smaller fibers mixed in. With such a construction, although a somewhat lower average fiber diameter than the preferred fiber diameter characterized above of 26 microns or greater would be involved, advantage could be taken of the two types of fibers with respect to the following: the large fibers could be used to provide rigidity and structure, i.e. resistance to collapse, to the overall systems; whereas the smaller fiber could be used to enhance efficiency. It is foreseen that when such mixtures are used, in general for the smaller diameter fibers, material having an average diameter of about 14 microns or less, typically about 8 to 13 microns, will be preferred.

In general, the type of media characterized in this section will be preferred for use in arrangements designed for accommodating at least some periods of operation under relatively high dust/high dirt situations, i.e. the class 2 type of dust classification characterized hereinabove. Thus, this media will, in general: (a)

be of less value if the arrangement is designed for strictly inner city, high carbon particle, applications; (b) be of greater value and desirability in the construction (as the most upstream layer) if the construction is for over the highway vehicles likely to encounter class 2 type circumstances at least portion of the time; and, (c) be of greatest desirability when the arrangement is designed for significant off-road use or use in similar environments, wherein high operating time periods in the presence of large amounts of class 2 type dust are anticipated. This would, in general, be the case regardless of whether or not the arrangement included a precleaner to preclassify the material. However, it can generally be understood that the more efficient the precleaner, the less there will be a preference for this higher loft material as opposed to alternate materials as characterized below.

2. Intermediate Loft Material.

Intermediate loft materials are also characterized in U.S. Patent 5,423,892, see for example, the disclosure at column 14, lines 10-59 and at column 23, lines 17-45, with material 7333 providing an example. In general, preferred such materials will have an average fiber diameter of at least about 16 microns and less than about 26 microns. In some instances, desirable products have an average fiber diameter within the range of 18-24 microns. Again, mixtures can be used allowing for the appropriate average diameters.

In general, preferred such materials will comprise polyester fibers, although alternate materials can be used for the fibers. A variety of dry laid materials which satisfy these criteria can be readily obtained from such sources and suppliers as Kem-Wove of Charlotte, North Carolina and Fiber Bond Corp. of Michigan City, Indiana.

Preferred materials will be ones having a "free state" solidity of no greater than about 3 percent, typically, no greater than 2 percent. The materials will generally be used, within filter constructions according to the present invention, under an appropriate amount of compression to provide for a percent solidity of this material within the arrangement of no greater than about 7 percent, and typically less than 4 percent, usually about 1.2 - 2.4 percent.

In order to accommodate this, in general, the materials will be utilized from mats or rolls providing the material in a form having a free state thickness of no greater than about 0.75 inches and typically about 0.5 inches or less. If a greater thickness of the material within the construction is desired, then the free state thickness of such mats or rolls, more than one layer of the material will typically be utilized. In the construction, the material will be compressed somewhat, typically to a thickness of about 0.2 to 0.3 inches (average) for each layer or wrap used, if the free state thickness is relatively low (especially if 0.5 inches or less); or about 0.4-0.6 inches if the free state thickness is relatively high (about 0.6-0.75 inches).

As is explained in U.S. Patent 5,423,892, this type of material can be used to provide for a higher efficiency of filtering, than the type of material characterized in section I1 above. This is due to the smaller fiber sizes, and, in some instances, a higher percent solidity of use within the construction.

Since the material has a higher efficiency, it will generally be most desired to use the material under one or the other of the following circumstances:

(a) as a material downstream from the material of section I1 above, in order to provide for gradient of efficiency (increasing) as the air passes through the depth media portion of the filter element; or

(b) as the most upstream layer, when relatively high load from high dust environments is not anticipated, and thus there is less need for a higher load, less efficient, outer or upstream layer in order to prevent premature occlusion or restriction increase.

3. Relatively High Efficiency Depth Media.

Preferred material for this use, will also comprise a fibrous depth media. This material should be of a type which will provide a relatively high efficiency, and will typically be used downstream from at least the intermediate material characterized in section I1 above. Preferred materials of the type characterized in this section will comprise dry laid polyester fibers, although alternate materials can be used. Typically, such materials, when for use in this layer, will have fiber sizes (average) of no greater than about 18 microns, typically no

more than 16 microns, and most often within the range of about 12 to 15 microns. Materials of mixed fibers, with overall averages as stated, can be used. These types of materials can be readily obtained from Kem-Wove of Charlotte, North Carolina or Fiber Bond Corp. of Michigan City, Indiana.

The preferred materials will be ones which have a "free state" solidity of no greater than about 5 percent, and typically no greater than about 3 percent. In general, they will be utilized to provide regions within the filter construction having a percent solidity, within the construction, of no greater than about 2.8 percent and typically no greater than about 2.5 percent, usually within the range of 1.8-2.4 percent (average), and preferably higher than any upstream region therefrom.

For preferred applications according to the present invention, the material will be obtained from a source which can provide the material in mats or rolls providing for a free state thickness of 0.12 to 0.30 inches and typically about 0.25 inches or less; and, thicknesses (of each layer or wrap) within the construction on the order of 0.1 to 0.25 inches. Again, as with previous materials, if a greater thickness of such media is desired, within the overall construction, than can be provided from one layer of such a material, it is anticipated that multiple layers or wraps will be utilized.

This relatively high efficiency, low fiber diameter, material, by comparison to the materials characterized in sections I1 and I2 above, is generally not appropriate media for use in the most upstream portion of air filters within air cleaner arrangements according to the present invention. A reason for this is that such materials provide for too high an efficiency of filtering, and would readily occlude. However, as a result of using upstream media as characterized, and thus classifying the material which eventually reaches such media, the I3 media can be efficiently and effectively utilized to provide for relatively high efficiency without an acceptably high restriction, both initial restriction and overall average restriction.

4. The Pleated Media.

A wide variety of pleated media can be utilized in arrangements according to the present invention. In general, cellulose fiber media or media comprising cellulose fibers and synthetic fibers will be preferred. However, it is

anticipated that purely synthetic arrangements may, eventually, be desired. With present technology and sources of materials available, in general it is anticipated that pleated paper material would be utilized in many instances.

Appropriate media for preparation in the pleated configuration, can be obtained from a variety of paper filter manufacturers such as Hollingsworth and Vose, East Walpole, Massachusetts.

A particular preferred characteristic with respect to the media will be its permeability. Especially with media used in "downsized" arrangements (high approach velocity or low volume) as generally characterized herein, paper media having a permeability of at least 30 fpm, and typically and preferably about at least 40 fpm and most preferably within the range of 50 fpm to 60 fpm, prior to any treatment (oiling or application of fine fibers thereto) will be preferred. Preferably a cellulose media having a basis weight of 50-80 lbs./3000 ft^2 and a thickness of 0.010 - 0.018 inch is used. Permeability will generally be as defined by the test standards characterized above.

In general, the barrier media will be pleated to a pleat depth of no more than 1.125 inches, typically no more than 0.75 inches but at least 0.25 inches and usually in 3/8 inch or 5/8 inch pleats. In many applications, 5/8 inch pleats will be preferred.

As was characterized above, in many applications it will be preferred to treat the media, prior to pleating, in order to increase efficiency. In U.S. Patent 5,423,892, several types of treatment to provide were characterized. One of these was "oiling" as indicated generally in the '892 patent at column 28, line 49 - column 29, line 6; and at column 32, lines 37-47.

In many preferred arrangements according to the present invention, it will be desirable to use a "dry" media, i.e. a non-oiled media. Especially in the low media volume or high approach velocity arrangements as characterized herein, dry media will be preferred. It will also be preferred to use the relatively high perm media, i.e. at least 40 or 45 fpm, as the pleated media, in order to provide for a lower initial restriction. However, for arrangements according to the present invention, especially the low media volume or high approach velocity arrangements, a principal function of the pleated media is in order to provide for an appropriately high

efficiency to meet engine or vehicle specifications. Thus, the relatively high perm media needs to be increased in efficiency, preferably without oiling.

This can be readily accommodated utilizing techniques also characterized in U.S. Patent 5,423,892 at column 32, line 48-60. More specifically, in the '892 patent at this location, reference is made to applying, to the upstream side of the media, a relatively fine fiber deposit in order to increase efficiency. The term "fine fiber" in this context is meant to refer to fiber application where the individual fibers have average diameters on the order of about 5 microns or below, in some instances submicron. The particular method of fiber formation deposition and material utilized are not critical factors; the purpose of the fine fiber layer being to generally increase efficiency. By using a combination of fine fibers and high porous or high permeability paper, an overall preferred arrangement without an undue restriction increase can be obtained. In general, final permeability of high perm papers having fine fibers applied thereto in certain preferred arrangements according to the present invention will still have permeabilities on the order of about 15 fpm or greater, typically about 20 fpm to 35 fpm.

The precise amount of fine fiber deposit utilized will depend upon the overall efficiency desired for the arrangement. In general, it will be selected by the engineer designing the filter arrangement, depending upon the particular specification decided upon by the engine manufacturer or vehicle manufacturer. All that is generally required is for the engineer to increase the amount of fine fiber deposit until the overall media pack meets the specification required. As indicated above, this can generally be done without implementing undesirable levels of increases in restriction.

5. <u>The Most Downstream Depth Media.</u>

The depth media characterized in this section is the optional region of media positioned downstream from the pleated media. For forward flow arrangements, this would be the region of media positioned along the inside of the pleated media, abutting the inner pleat tips. The media located at this location serves two principal functions:

(a) it can facilitate the manufacturing and protects the pleated media from pleat tip wear;

(b) it can provide for relatively small but significant increases in overall efficiency without substantial added restriction.

The desirable media for this application will depend in part on whether the media is primarily present for its protection purpose, or whether it is also being used to increase efficiency.

If the primary function of the media is to provide for protection of the pleated media without significant increase in efficiency of the overall system, it will be generally desired to use a very open material that does not have a very high efficiency but which, as a result, will add relatively little to the initial restriction of the design. Such a media for example would be of the type characterized in section I1 above, for example a material available from Fiber Bond, Inc., having a basis weight of 4.2 oz/yd^2, an average thickness (free state) of about 0.34 inches; an average fiber diameter of 27 microns and an average permeability of 1100-1200 fpm.

On the other hand, if an increase in efficiency is desired, and the resulting increase in restriction is acceptable in the overall design, a relatively high efficiency media such as described in section I3 may be preferred for this location.

In some instances it may be desirable to use especially thin layers of depth media in this region, by comparison to other regions.

6. Optional Alternate Stages

It is foreseen that in some instances, optional alternate stages to those described may be desired. A specific location in which it is foreseen that certain such stages may be desirable, would be positioned immediately upstream from the pleated barrier filter. In this location it may be desired to use even a higher efficiency media, than characterized in I.3. above.

This can be accomplished, for example, by using a material such as that characterized in Section I.3., but compressed even higher than described therein. As an alternative, a material relatively high solidity and relatively fine fiber diameter could be used. For example, media on the order of about 1-10 micron average fiber

diameter, typically about 2-5 micron, with a percent solidity on the order of about 3-7%, typically about 5%, can be used to provide for an overall relatively efficient layer immediately upstream from the pleated material.

In addition, alternate constructions can be utilized which do not use a pleated barrier material therein, but rather only use layers of depth media, generally with an increase in gradient, from upstream to downstream, to achieve a desired level of efficiency and restriction. In general, the same types of materials is characterized herein with respect to depth media, can be used to accomplish these desirable arrangements.

J. Certain Preferred Media Pack Specifications

As examples to indicate how the techniques described hereinabove can be utilized in arrangements according to the present invention, in this section, specifications for preferred media arrangements are provided.

The design presented in this section allows for the following types of criteria to be readily met; when the geometry given below is provided. The description is of a forward flow arrangement. Thus, the outer liner is most upstream.

1. Minimum overall efficiency based on SAEJ 726 protocol of at least 99.80%;

2. Minimum initial efficiency based on SAEJ 726 protocol of at least 98.5%;

3. An initial restriction of less than 3 inches of water at an air flow of 600 cubic feet per minute, and generally at an air flow on the order of about 700 cubic feet per minute or less.

4. An initial restriction of no greater than about 8 inches of water at air flows up to about 1200 cubic feet per minute.

Three preferred media pack recipes or formulations are characterized in Table 1 below.

TABLE 1

Media Pack #1	Media Pack #2	Media Pack #3
Outer liner [a]	Outer liner [a]	Outer liner [a]
1st Depth Media Layer[b]	1st Depth Media Layer[b]	1st Depth Media Layer[c]
2nd Depth Media Layer[c]	2nd Depth Media Layer[c]	2nd Depth Media Layer[d]
3rd Depth Media Layer[d]	3rd Depth Media Layer[d]	3rd Depth Media Layer[d]
Pleated Media Layer[e]	Pleated Media Layer[e]	Pleated Media Layer[e]
4th Depth Media Layer[f]	4th Depth Media Layer[h]	4th Depth Media Layer[f or h]
Inner Liner[g]	Inner Liner[g]	Inner Liner[g]

a Galvanized expanded metal at least 50% open, preferably at least 60% open area. Typical ones are 70-90% open with a negligible pressure drop thereacross at 0.1 in H_2O.

b Media of the type characterized in section I1. Preferably average solidity within the construction of 1.1-1.5 percent. Preferably about 0.30-0.40 inch thick in the construction.

c Media of the type characterized in section I2. Preferably average solidity within the construction of 1.5-2.0 percent. Preferably about 0.2-0.3 inch thick in the construction.

d Media of the type characterized in section I3. Preferably average solidity within the construction of 2.0-2.5 percent. Preferably about 0.1-0.25 inch thick in the construction.

e Barrier media of type characterized in section I4. Preferably pleated with submicron fibers applied thereto. Preferably 5/8 inch pleats. Perm before fine fiber application 50-60 fpm; after 20-30 fpm.

f. Media of type characterized in section I5, preferably of the type characterized in section I1. Typically, < 0.1 inch, typically about 0.03-0.05 inch thick, in the construction.

g Galvanized expanded metal at least 50% open, preferably at least 60% open, area. Typical ones are 70-90% open with a negligible pressure drop thereacross at 0.1 in H_2O.

h Media of type characterized in section I5, preferably of type characterized in section I3. Typically < 0.1 inch, preferably about 0.03-0.05 inch thick, in the construction.

It is noted that in one of the formulations given above, media pack number 3, two layers of the same media material, indicated at footnote d in table 1, are used. Whether or not more than one layer or wrap of media, for any given situation, and with respect to any region or layer, is appropriate, relates to evaluation on the part of the engineer of whether the "returns" of using such an extra layer are of significance. In some instances this can be done by evaluating the construction after laboratory testing or field testing. If there is not a significant amount of load observed in the more downstream of the two layers of identical material, then the additional layer was not providing significant benefit, by comparison to the added restriction and size that resulted from its presence. From this it can be seen that in many instances the desirability of added layers or doubling of layers, is based upon empirical observation. However, some of the preferred media formulations characterized herein in connection with the discussion of Table 1, and also hereinbelow in connection with other discussions, provide significant guidance.

For use with a truck having an air flow demand of 800-1200 cfm, an arrangement with an approach velocity of about 200 to 300 cfm and the construction could be made with the following geometry:

(a) an overall media construction thickness, liner to liner, of no more than about 2.25 inches and in some instances, about 1.0-1.75 inches. (For one

specific embodiment a total media pack thickness of about 1.5 inches was found desirable, with 0.035 inch thick liners.)

(b) an overall media pack length of about 14.75 inches including about 0.375-0.50 inches at each end embedded in end cap material.

(c) an overall outside diameter of about 10-13 inches, for example 10.28 inches.

(d) a media pack inside diameter of about 7-10 inches, for example 9.78 inches.

(e) an inside diameter to ring structure 23, Figs. 1 and 2, of 7.78 inches.

(f) a polyurethane foam end cap providing for sealing to an air flow tube having an outside diameter of about 7 inches.

(g) a polyurethane foam end cap providing for a region 15, Fig. 1, of minimum diameter (i.e. diameter of thickest portion to be compressed, during sealing 20-40%) of 6.78 inches, with steps of 6.84 inches and 6.91 inches.

In order to accommodate different engine flow demands, in general, the volume of the media pack can be adjusted to maintain approximately the same approach velocity. This can be accommodated without changing the basic "recipe" for the media pack by either: shortening the length of the media pack; or, by decreasing the inside diameter and outside diameter of the media pack, without changing media pack thickness and formulation. Of course, a combination of these variables can also be practiced. With these techniques, it is anticipated that media packs of the type characterized in Table 1 can be developed appropriate for use, for example, with engine demands of about 500 cfm or above during rated peak performance with approach velocities of greater than 200 fpm, preferably > 250 fpm, most preferably > 320 fpm.

For preferred arrangement, it is anticipated that the ring structure 23, Figs. 1 and 2 would be generally as characterized above, and constructed in the preferred materials preferred sizes and preferred thicknesses characterized above. One specific filter support 23 may be constructed with the following dimensions and materials: the outer most diameter between the outer most projecting tips of feet 36 may be about 8-15 inches (about 20-38 cm), typically about 9.78 inches (about 25 cm). The inner diameter of inner cylindrical wall 25 may be about 6-13 inches (about 15-33 cm), typically about 7.78 inches (about 20 cm). The length of inner cylindrical wall 25 may be between about 0.75 - 1.25 inches (about 19-32 mm), typically about 0.99 inches (about 25 mm). The overall axial length between tip 37 and end of wall 25 at point 34 may be about 1.1 - 1.6 inches (about 28-41 mm), typically about 1.32 inches (about 34 mm) (Thus the wall 25 projects at least 1.1 inch into the inernal volume of the media pack.). The height of each of feet 36 was about 0.15 - 0.2 inches (about 4-5 mm), typically about 0.17 inches (about 4.5 mm). At the inner section of projecting extension wall section 35 and wall 25, filter support 23 may have a radius surface on a radius about 0.04 - 0.08 inches (about 1-2 mm), typically about 0.06 inches (about 1.5 mm).

In embodiments where filter support 23 includes notches, there may be between 10-14 notches, typically 12 notches. Each of notches 43 would be constructed to have a width of about 0.1 - 0.4 inches (about 3-10 mm), typically about 0.25 inches (about 6 mm). Each of notches 43 would have a height or length of between about 0.1 - 0.4 inches (about 3-10 mm), typically about 0.25 inches (about 6 mm).

In embodiments where there are apertures 42, there may be between about 10-26 apertures, typically about 15-20 apertures. Each of apertures 42 would have a diameter of about 0.3-0.5 inches (about 8-13 mm), typically about 0.38 inches (about 10 mm). Each of the apertures 42 may be angled relative to an adjacent aperture, center-to-center, at about 10-30°, typically about 20°.

In embodiments where there are feet 36, there would be about 5-12 feet, typically about 8 feet. Each of feet 36 may be angled relative to an adjacent

one at an angle between about 35-55°, typically about 45°. Each of feet 36 may have a width of about 0.2-0.3 inches (about 5-8 mm), typically about 0.25 inches (about 6 mm).

Filter support 23 may be constructed from a plastic material, such as high impact polystyrene, having a thickness of about 0.05-0.1 inches (about 1-3 mm), typically about 0.08 inches (about 2 mm).

K. Preferred Approaches For Generating High Approach Velocity or Low Media Volume Arrangements

In general, the techniques used for developing a high approach velocity or low media volume arrangement would be generally analogous. As indicated above, the engineer would determine the appropriate face size by using the approach characterized in section H above, or media volume by using the formula indicated in section H above. This information, in combination with the internal diameter information resulting from the duct size, would tell the engineer, for a given engine air flow demand, the appropriate variable ultimately defining media volume and/or upstream liner surface area, and thus media upstream surface area.

The engineer would then "fill" the media volume available (or to be used) with gradient layers using materials of the type characterized in section I above, generally ordered as described in that section or analogously to the definition in section J above. (Although in some instances thinner depth media packs may be desirable.) This will, in general, result in an element which is "downsized" relative to conventional elements used in similar situations.

In general, it is foreseen that preferred thicknesses for the media volume will be on the order of 1.0 inch to 2.5 inches, preferably about 1.0 inches to 2.25 inches, in many instances 1.75 inches or less. Thus, if the outer media surface area is defined, based on approach velocity definitions; or, the overall media volume is defined, based upon low media volume definitions as characterized above, once the inlet diameter is fixed by the duct size, and or safety element size, use of the preferred thickness as characterized in the previous sentence, will allow definition

the outside diameter of the preferred construction. Also, based on the formulae provided herein, the engineer can define either light duty, medium duty or heavy duty elements, for any given application.

In general, preferred ordering of materials within the media pack will generally be as characterized in Table 1 above or generally according to the characterizations found in Sections I - K above. Preferably high loft, less efficient, higher load media will be used toward the upstream portion of the media pack, with a gradient tending toward higher efficiency, lower loft, lower load (in use) media further downstream in the depth media pack (upstream from the barrier media). Also, preferably, pleated barrier media, most preferably a high perm media with a fine fiber application on an upstream surface thereof, will be positioned within the arrangements, and generally downstream from a multilayer, gradient, depth media pack. In most preferred systems, a fibrous mat will also be used downstream from the pleated barrier construction, this material being chosen to be low efficiency or high efficiency depending on the overall efficiency demands to the system, and restriction limitations. In general, the engineer will modify the efficiency of the system in order to accommodate overall efficiency or restriction demands, in some instances by modifying the amount of fine fiber material deposited upon the upstream surface of the pleated media or otherwise modifying the pleated media construction.

In general, with techniques as characterized in this section, it is foreseen that a wide variety of preferred designs for various engine demands can be developed. For example, it is foreseen that arrangements for use with engine air flow (rated) demands for over-the-highway, inner city trucks and buses, on the order of about 500 to 2000 cfm, can be readily accommodated. These can be with, or without, some type of precleaner involved. When high dust environments such as off-road, construction site, agricultural site or mining sites are anticipated, it may be desirable to use rigorous precleaner systems and/or to use relatively high volumes of the higher perm material, to accommodate load.

In Fig. 4, a general characterization of an air filter element positioned for operation in a forward flow system is depicted schematically generally at 100. In Fig. 4, a cylindrical filter element 101 is shown with first and second end caps 102, 103 and a cylindrical extension of media 104 in extension between first and second end caps 102, 103. Media construction 104 defines an open interior 105 within. An air cleaner housing is shown in phantom at 106. Air cleaner housing 106 could be one of a variety of air cleaner housing constructions. In the embodiment shown in phantom, air cleaner housing 106 includes an air inlet tube 107. In general, in a forward-flow operation, air to be filtered is drawn through the air inlet tube 107, depicted by arrow 108. The air flows through media pack 104 and into the open filter interior 105. The clean air then flows from the filter interior 105, depicted at arrows 109 and out through an air flow outlet tube construction in the air cleaner housing 106.

Still in reference to Fig. 4, filter element 101 includes an outer liner 120 and an inner liner 121, extending between the first and second end caps 102, 103. Liners 120, 121 typically function to support media construction 104 therein. The area of liner 120 divided into the rated air flow demand, would be the approach velocity.

First end cap 102 defines a radial sealing surface 122 for interfacing and engaging with an outlet tube construction.

The air flow shown at arrow 108 depicts generally the direction of air force approach as it flows through element 101 and media pack 104.

Attention is now directed to Fig. 5. In Fig. 5, an air cleaner arrangement is shown generally at 115. In Fig. 5, an example air cleaner housing is shown at 116, and includes an air flow inlet tube 117 and an air flow outlet tube 118. Air filter element 101 is shown in cross-section, oriented within housing 116. Air flow outlet tube 118 snaps into housing 116 and projects into the filter interior 105. As such, outlet tube construction 118 interfaces and engages radial sealing surface 122 of first end cap 102 to form a radial seal 123 therebetween.

In reference now to Fig. 6, a fragmented, cross-sectional view of first end cap 102 is depicted. In particular, radial sealing surface 122 is shown, in an uncompressed state. That is, radial sealing surface 122 is shown when filter element 101 is not installed in air cleaner housing 116 and over tube 118.

Still referring to Fig. 6, radial sealing surface 122 defines a gradient of increasing internal diameters of surfaces for interfacing with an air flow outlet tube, e.g., outlet tube construction 118. Specifically, in the example shown in Fig. 6, radial sealing surface 122 defines three steps, 125, 126, and 127. The cross-sectional dimension or width of the steps increases, the further the step is from a top portion 128 of the first end cap 102. As shown, below step 127, there is a region 129 of decreased cross-sectional width.

Turning now to Figs. 7 and 8, two example, preferred media packs are illustrated. In Fig. 7, media pack 150 is shown schematically as a layered construction. An outermost layer is an outer liner 151, such as an expanded or perforated metal or plastic, for supporting filtering media. The next layer immediately adjacent to outer liner 151 and downstream of outer layer 151 in a forward flow arrangement is layer 152. Outer (upstream) layer 152 may comprise a high load, high velocity, low solidity depth media, such as that described above at I1 or an intermediate load material as described above at I2.

Immediately adjacent to layer 152 and downstream of 152 in forward flow arrangements is layer 153. Layer 153 may preferably comprise an intermediate loft material, such as that described above at I2 or a higher efficiency layer as described above at I3. In general, a step in efficiency (increase) between regions 151 and 152 will be preferred, and the media should be selected, or arranged, accordingly.

Adjacent to layer 153 and immediately downstream of layer 153 in a forward flow system is layer 154. Layer 154 is preferably a high efficiency fibrous depth media, as described above at I3. In some instances a step in efficiency (increase) between regions 152 and 153 will be preferred. When such is the case, the media should be selected, or arranged, accordingly.

Adjacent to layer 154 and downstream of layer 154 in forward flow systems is layer 155. Layer 155 is preferably a pleated media, with high surface loading. One example of preferred media is that as described above at I4.

Adjacent to layer 155 and downstream of layer 155 in forward flow systems is layer 156. Media layer 156 preferably comprises the most downstream depth media and is preferably of the type characterized above at I5.

Adjacent to and supporting layer 156 and downstream therefrom is an inner liner 157. Inner liner 157 is typically of the same construction as outer liner 151.

In Fig. 8, another media pack is schematically shown generally at 170. In this embodiment, the most upstream construction is outer liner 171, with the most downstream construction being inner liner 172. Inner and outer liners 171, 172 may each comprise an expanded metal or perforated metal, for supporting the filtering media therebetween.

Adjacent to outer liner 171 and immediately downstream therefrom is layer 173. Downstream from this are depth media layers 174, 175 and 176. Next is pleated barrier region 177 and finally internal depth media region 178. In general, principles described herein can be used for selection of media in these regions, the point to Fig. 8 being to indicate that a variety of numbers of depth media layers upstream from the barrier media region can be used.

It is noted that the color of the media maybe selected depending on choice, in many instances. Donaldson Company, Inc., the assignee of the present application, will in some instances prefer to utilize as the depth media in the outermost region of the cylindrical construction a media which is colored the distinctive, Donaldson, source identifying color, blue.

L. Safety Filters.

In general, principles described herein can be utilized in arrangements having no secondary or safety filter, as well as arrangements having such secondary filters or safety filters. In general, a secondary filter or safety filter is typically an

element secured in place on a downstream side of the primary filter element. In arrangements using Donaldson radially sealing arrangements on the primarily filter element, the secondary filter or safety filter is generally positioned with an end secured to the inside of the outlet tube, and a remainder as the safety element positioned in longitudinal extension along the open internal volume of the primary filter.

With respect to the safety filter, attention is directed to Fig. 5. Although in Fig. 5 no safety element is depicted, the outlet tube 118 depicted in Fig. 5 includes a shoulder 500 whereat a safety element would typically be positioned. Safety elements of the type used for an arrangement such as shown in Fig. 5, with a shoulder such as shoulder 500, are generally cylindrical, pleated barrier filter, arrangements. These will typically have pleat depths of 0.38-1.5 inches, depending on the system. In other instances, especially with relatively low flow demand systems, or small air cleaner constructions, safety filters comprising a cylindrical tube of depth media are used.

Again, the principles discussed hereinabove with respect to primary filter design, can be used for primary filters used both with such safety elements or used alone. It is noted that in some instances, modifications in primary filter element design may be used, to reduce restriction, if the safety filter design chosen is one in which contributes to any significant extent to the initial restriction.

M. <u>Systems and Methods of Use.</u>

In Fig. 10, a schematic view of a system is shown generally at 200. System 200 is one example type of system in which air cleaner arrangements and constructions described herein is usable. In Fig. 10, equipment 202, such as a vehicle, having an engine 203 with some defined rated air flow demand is shown schematically. Equipment 202 may comprise a bus, an over the highway truck, an off-road vehicle, a tractor, or marine application such as a power boat. Engine 203 powers equipment 202, through use of an air, fuel mixture. In Fig. 10, air flow is shown drawn into engine 203 at an intake region 205. An optional turbo 206 is shown in phantom, as optionally boosting the air intake into the engine 203. An air cleaner 210 having a media pack 212 is upstream of the engine 203 and turbo 206.

In general, in operation, air is drawn in at arrow 214 into the air cleaner 210 and through media pack 212. There, particles and contaminants are removed from the air. The cleaned air flows downstream at arrow 216 into the intake 205. From there, the air flows into engine 203, to power vehicle 202.

Table II below indicates general guidelines for construction of preferred filter elements for commercial applications according to certain applications of the principles characterized hereinabove. It is noted that applications in the defense market equipment would utilize similar characteristics and guidelines.

The first column in the table refers to equipment type. In general, class 1 trucks would include: minivans, utility vans, multi-purpose vans, minipickups, and full size pickup trucks. Class 2 trucks would generally include certain minivans or utility vans, compartment pickup trucks, selected full size pickup trucks and minibuses. Class 3 trucks would include minibuses, walk-in trucks and city delivery trucks. Class 4 trucks would include conventional vans, large walk-in trucks, city delivery trucks, landscaping utility trucks and equipment. Class 5 trucks would generally include large walk-in trucks, city delivery trucks and trucks. Class 6 trucks would generally include rack trucks, single axle vans, beverage trucks, school buses and state vehicles. Class 7 trucks would generally include home fuel trucks, refuse trucks, tow trucks, city transit buses, furniture vans and trucks, medium conventional trucks and high profile COE. Class 8 trucks would generally include fuel trucks, dump trucks, cement trucks, refrigerated vans, inner city/tour buses, fire engines, heavy conventional trucks and COE sleepers. Off highway agricultural applications would generally include two wheel tractors, agricultural mowers, agricultural tractors, balers, combines, irrigation sets, sprayers and swathers. Off highway construction equipment would generally include such equipment as bore/drill rigs, cement/mortar mixers, cranes, crawler dozers, crawler loaders, dumpers/tenders, excavators, forest equipment, graters, off highway tractors, off highway trucks, pavers and paving equipment, plate compactors, rollers, rough terrain fork lifts, rubber tire dozers, rubber tire loaders, scrapers, skid/steer loaders, tamper/rammers, tractor/loader/backhoe; trenchers and underground mining equipment. Off highway general industrial equipment would generally include: aircraft support, chipper/grinders, concrete/industrial saws, crush/processing

equipment, locomotives, oil field equipment, railway maintenance equipment, scrubber/sweepers and surfacing equipment. Off highway marine applications would generally include: commercial marine engines, outboard engines, power boats and sailboat auxiliary engines. Off highway material handling equipment would generally include: aerial lifts, forklifts and terminal tractors. Off highway pump/compression equipment would generally include: air compressors, gasket presses, hydraulic power units, pressure washers and pumps. Finally, off highway-welders/generators would generally include generator sets, lt plants, marine or auxilliary generators and welders.

In Table II below, certain observations are made with respect to the media formulation. The designations indicated in the columns, have the following meaning and intent:

A. This type of equipment is often fitted with light duty (or sometimes medium duty) air cleaners and air filter elements. As a result of the relatively thin media thicknesses involved, it will typically be preferred to use a media construction or media pack which, if it has any pleated material at all therein, has a pleated material which has relatively low pleat depth, typically less than 1/2 inch and generally about 3/8 inches. The remainder of the media pack would generally be filled with depth media as characterized hereinabove. In some instances, little, if any, of the relatively high loft, I1, material will be used, due to the limited space. Of course heavy duty applications can be constructed as well.

B. In these types of instances, the thicker media volumes allow for the use of relatively large pleat depth, on the order of about 0.5-0.75 inches, typically about 5/8 inches. With medium duty or heavy duty element designs, an outermost layer comprising the relatively high loft material will be preferred. Of course light duty designs can also be constructed.

C. This is the typical off highway or off road system, medium duty. The internal diameter, when a forward flow arrangement is involved, will be designed to accommodate the presence of a safety filter. The relatively thick media pack would typically and preferably include pleated media with a pleat depth of about 0.5-0.75 inches, and a plurality of layers of depth media, generally with the outermost including a relatively high loft, high load, material of the type

characterized in Section I1, and with the innermost depth media in the region upstream from the pleated barrier material, comprising a relatively high efficiency fibrous depth material, for example as characterized in Section I3 and in some instances as characterized in Section I6. Of course, light duty or medium duty designs could also be made.

According to the present invention, general methods of filtering are provided, which methods generally involve application to principles hereinabove with constructions as described. In addition, methods of designing filter elements for selected situations are presented. Finally, a method of rejuvenating an air cleaner comprising changing a used filter element within the air cleaner, for a filter element as generally characterized herein, is provided.

TABLE 2

COMMERCIAL APPLICATIONS GUIDELINES

Equipment Type	Engine Displ. (cu. in./liters)	Rated Engine Airflow Demand (cfm)	Low Vol. Element Media Vol. (cu. in.)	Outer Liner Surface Area (sq. ft.)	Element I.D. (in.)	Approach Velocity (fpm)	Media Thickness (in.)	Media Formulation
Class 1 Truck (6,000 lbs. and less)	100-500 cu. in. 1.6-8.1 liters	45-500	<113 prefer 85-103	<0.85 prefer 0.64-0.78	4.04	<781 prefer 588-641	1.12	A
Class 4 Truck (14,001-16,000 lbs. GVW)	190-507 cu. in. 3.1-8.3 liters	370-1,000	<212 prefer 159-194	<1.54 prefer 1.15-1.41	5.50	<870 prefer 649-709	1.12	A
Class 6 Truck (19,501-26,000 lbs. GVW)	350-610 cu. in. 5.7-10.0 liters	680-1200	<255 prefer 192-234	<1.81 prefer 1.36-1.66	6.00	<882 prefer 663-723	1.12	A
Class 8 Truck (33,001 lbs. GVW and over)	507-854 cu. in. 8.3-14.0 liters	1,000-1660	<702 prefer 527-644	<3.77 prefer 2.84-3.47	7.00	<585 prefer 440-478	1.50	B
Off Highway-Construction	507-854 cu in. 8.3-14.0 liters	1000-1660	<702 prefer 527-644	<3.77 prefer 2.84-3.47	7.00	<585 prefer 440-478	1.50	C

CLAIMS:

1. A system including an engine rated at an engine intake air flow of at least 370 cfm and having an air cleaner constructed and arranged to filter the engine intake air; the air cleaner including a primary filter element operably positioned therein, the primary filter element being characterized by:

(a) a size defining an approach velocity of at least 380 fpm, under the engine rated air flow;

(b) an overall operating efficiency of at least 99.5%, when evaluated by SAEJ726;

(c) a media construction thickness of no greater than 2.5 inches; and,

(d) a media construction including:

(i) an upstream depth media portion; and,

(ii) a pleated barrier media construction positioned downstream from the upstream depth media portion.

2. A system according to claim 1 wherein:

(a) the system includes an engine rated at an engine intake air flow of at least 500 cfm; and

(b) the primary element has a size and construction providing for an initial restriction of no great than 3 inches of H_2O, when evaluated at air flow rates of up to 600 cfm.

3. A system according to any one of claims 1 and 2 wherein:

(a) the primary filter element is characterized by a size defining an approach velocity of at least 420 fpm, under the engine rated air flow.

4. A system according to any one of claims 1 through 3 wherein:

(a) the primary filter element is characterized by a size defining an approach velocity of at least 450 fpm, under the engine rated air flow.

5. A system according to any one of claims 1 through 4 wherein:

(a) the primary filter element is characterized by a size defining an approach velocity of at least 588 fpm, under the engine rated air flow.

6. A system according to any one of claims 1 through 5 wherein:

(a) the primary filter element is constructed and arranged for an initial efficiency of at least 98%, when evaluated by SAEJ726.

7. A system according to any one of claims 1 through 6 wherein:

(a) the primary filter element is constructed and arranged for an initial efficiency of at least 98.5%, when evaluated by SAEJ726.

8. A system according to any one of claims 1 through 7 wherein:

(a) the primary filter element is constructed and arranged for an overall efficiency of at least 99.8%, when evaluated by SAEJ726.

9. A system according to any one of claims 1 through 8 wherein:

(a) said pleated barrier media comprises a pleated cellulose fiber media having a fiber deposit on at least one surface thereof;

(i) said fiber deposit having an average fiber size of no greater than 5 microns.

10. A system according to claim 9 wherein:

(a) said pleated barrier media comprises a pleated cellulose media which, prior to application of said fiber deposit thereto, had a permeability of at least 35 fpm.

11. A system according to claim 10 wherein:

(a) said pleated barrier media comprises a pleated cellulose media which, prior to application of said fiber deposit thereto, had a permeability of at least 45 fpm; and which, after application of said fiber deposit thereto, has an overall permeability of no greater than 35 fpm.

12. A system according to claim 11 wherein:

(a) said pleated barrier media comprises a pleated cellulose media which, prior to application of said fiber deposit thereto, had a permeability of at least 50 fpm; and which, after application of said fine fiber deposit thereto, has an overall permeability of no greater than 30 fpm.

13. A system according to any one of claims 1 through 12 wherein:

(a) said pleated barrier media has a pleat depth of no greater than 1.125 inches.

14. A system according to any one of claims 1 through 13 wherein:

(a) said pleated barrier media has a pleat depth of no greater than .75 inches.

15. A system according to any one of claims 1 through 14 wherein:

(a) said pleated barrier media has a pleat depth within the range of 0.25 to 0.75 inches.

16. A system according to any one of claims 1 through 15 wherein:

(a) said upstream depth media portion includes at least first and second regions of fibrous depth media which differ from one another with respect to efficiency.

17. A system according to any one of claims 1 through 16 wherein:

(a) said upstream depth media portion includes three regions of fibrous depth media which differ from one another with respect to efficiency.

18. A system according to any one of claims 1 through 17 wherein:

(a) said upstream depth media portion includes at least first and second regions of fibrous depth media which differ from one another with respect to average fiber size.

19. A system according to any one of claims 1 through 18 wherein:

(a) said upstream depth media portion includes three regions of fibrous depth media which differ from one another with respect to average fiber size.

20. A system according to any one of claims 1 through 19 wherein:

(a) said upstream depth media portion includes at least first and second regions of fibrous depth media which differ from one another with respect to average fiber size;

(i) a first region having a first average fiber size being positioned upstream from a second region having a second average fiber size;

(ii) said second average fiber size being smaller than said first average fiber size.

21. A system according to any one of claims 1 through 20 wherein:

(a) said upstream depth media portion includes first, second and third regions of fibrous depth media which differ from one another with respect to average fiber size;

(i) a first region having a first average fiber size being positioned upstream from a second region having a second average fiber size;

(ii) said second region being positioned upstream from a third region having a third average fiber size;

(iii) said first average fiber size being greater than said second average fiber size; and,

(iv) said second average fiber size being greater than said third average fiber size.

22. A system according to any one of claims 1 through 21 wherein:

(a) said media construction has a thickness of no greater than 2.25 inches.

23. A system according to any one of claims 1 through 22 wherein:

(a) said media construction has a thickness of no greater than 2 inches.

24. A system according to any one of claims 1 through 23 wherein:

(a) said media construction has a thickness within the range of 1-1.75 inches.

25. A system according to any one of claims 1 through 24 wherein:

(a) the primary element has a media volume of no greater than the rated engine air intake flow in cubic feet per minute divided by 2737 min^{-1}.

26. A system according to any one of claims 1 through 25 wherein:

(a) the primary element has a media volume of no greater than the rated engine air intake flow in cubic feet per minute divided by 2985 min^{-1}.

27. A system according to any one of claims 1 through 26 wherein:

(a) the primary element has a media volume of no greater than the rated engine air intake flow, in cubic feet per minute, divided by 3100 min^{-1}.

28. A system according to any one of claims 1 through 27 wherein:

(a) the primary element has a media volume within a range defined by the rated engine air intake flow divided by:

(i) 3285 min^{-1}; and

(ii) 3100 min^{-1}.

29. A system according to any one of claims 1 through 28 wherein:

(a) the system is an on-road vehicle; and,

(b) the media construction is constructed and arranged for installation and air cleaner operation over a mileage of normal vehicle use of at least 40,000 miles, without refurbishing or replacing the primary filter element and without an overall restriction, across the air cleaner, exceeding a selected value between 20 and 30 inches of H_2O.

30. A system according to any one of claims 1 through 29 wherein:

(a) the media construction is constructed and arranged for installation and air cleaner operation over a mileage of normal vehicle use of at least 50,000 miles, without refurbishing or replacing the primary filter element and without an overall restriction, across the air cleaner, exceeding a selected value between 20 and 30 inches of H_2O.

31. A system according to claim 30 wherein:

(a) the selected value, of the overall restriction that is not exceeded, is 25 inches of H_2O.

32. A system according to any one of claims 1 through 28 wherein:

(a) the system is selected from stationary equipment and off-road vehicles; and,

(b) the media construction is constructed and arranged for installation and air cleaner operation over an operating period of normal equipment use, of at least 225 hours, without refurbishing or replacing the primary filter element and without an overall restriction, across the air cleaner, exceeding a selected value between 20 and 30 inches of H_2O.

33. A system according to claim 32 wherein:

(a) the media construction is constructed and arranged for installation and air cleaner operation after an operating period, of normal equipment use, of at least 250 hours, without refurbishing or replacing the primary filter element and without an overall restriction, across the air cleaner, exceeding a selected value between 20 and 30 inches of H_2O.

34. A system according to claim 33 wherein:

(a) the selected value, of the overall restriction, that is not exceeded, is 25 inches of H_2O.

35. A system according to claim 1 wherein:

(a) the system is a truck having a GVW of at least 6,000 lbs.

36. A system according to claim 35 wherein:

(a) the system is a truck having GVW of at least 14,001 lbs.

37. A system according to any one of claims 1 through 31 and 35 through 36 wherein:

(a) the system is a truck having a GVW of at least 19,501 lbs.

38. A system according to claim 37 wherein:

(a) the system includes an engine rated at an engine intake air flow of at least 680 cfm.

39. A system according to claim 38 wherein:

(a) the system includes an engine rated at an engine intake air flow within the range of 680-1200 cfm.

40. A system according to any one of claims 1 through 39 wherein:

(a) the primary filter element is constructed and arranged to have an approach velocity of less than 882 fpm.

41. A system according to claim 40 wherein:

(a) the primary filter element is constructed and arranged to have an approach velocity within the range of 663-723 fpm.

42. A system according to any one of claims 1 through 41 wherein:

(a) the primary element has an outer liner with an outer liner surface area of less than 1.81 sq. ft.

43. A system according to claim 42 wherein:

(a) the primary element has an outer liner with an outer liner surface area within the range of 1.36-1.66 sq. ft.

44. A system according to any one of claims 1 through 43 wherein:

(a) the primary element has a media volume of less than 255 cubic inches.

45. A system according to claim 44 wherein:

(a) the primary element has a media volume within the range of 192-234 cubic inches.

46. A system according to claim 1 wherein:

(a) the system includes an engine rated at an engine intake air flow demand of at least 1,000 cfm.

47. A system according to claim 46 wherein:

(a) the system is a truck having a GVW of at least 33,001 lbs.

48. A system according to claim 47 wherein:

(a) the system includes an engine rated at an engine intake air flow demand within the range of 1000-1660 cfm.

49. A system according to any one of claims 46 through 48 wherein:

(a) the media construction is constructed and arranged to have an approach velocity of less than 585 fpm.

50. A system according to any one of claims 46 through 49 wherein:

(a) the media construction is constructed and arranged to have an approach velocity of no greater than 478 fpm.

51. A system according to any one of claims 46 through 50 wherein:

(a) the media construction is constructed and arranged to have an approach velocity within the range of 440-478 fpm.

52. A system according to any one of claims 46 through 51 wherein:

(a) the media construction includes an outer liner and has an outer liner surface area of less than 3.77 sq. ft.

53. A system according to any one of claims 46 through 52 wherein:

(a) the media construction includes an outer liner and has an outer liner surface area of less than 3.47 sq. ft.

54. A system according to any one of claims 46 through 53 wherein:

(a) the media construction includes an outer liner and has an outer liner surface area within the range of 2.84-3.47 sq. ft.

55. A system according to any one of claims 46 through 54 wherein:

(a) the media construction has a media volume of less than 702 cubic inches.

56. A system according to any one of claims 46 through 55 wherein:

(a) the media construction has a media volume of no greater than 644 cubic inches.

57. A system according to any one of claims 46 through 56 wherein:

(a) the media construction has a media volume within the range of 527-644 cubic inches.

58. A system according to claim 1 wherein:

(a) the primary element has a media volume of no greater than the rated engine air intake flow in cubic feet per minute divided by 1369 min^{-1}.

59. A system according to claim 58 wherein:

(a) the primary element has a media volume of no greater than the rated engine air intake flow in cubic feet per minute divided by 1493 min^{-1}.

60. A system according to claim 59 wherein:

(a) the primary element has a media volume of no greater than the rated engine air intake flow in cubic feet per minute divided by 1550 min^{-1}.

61. A system according to claim 60 wherein:

(a) the primary element has a media volume within a range defined by the rated engine air intake flow divided by:

(i) 1643 $min.^{-1}$; and,

(ii) 1550 $min.^{-1}$.

62. A system according to any one of claims 58 through 61 wherein:

(a) the system is an on road vehicle; and,

(b) the media construction is constructed and arranged for installation and air cleaner operation over a mileage of normal vehicle use of at least 90,000 miles, without refurbishing or replacing the primary filter element and without an overall restriction, across the air cleaner, exceeding a selected value between 20 and 30 inches of H_2O.

63. A system according to claim 62 wherein:

(a) the system is an on road vehicle; and,

(b) the media construction is constructed and arranged for installation and air cleaner operation over a mileage of normal vehicle use of at least 100,000 miles, without refurbishing or replacing the primary filter element and without an overall restriction, across the air cleaner, exceeding a selected value between 20 and 30 inches of H_2O.

64. A system according to claim 63 wherein:

(a) the selected value, of the overall restriction that is not exceeded, is 25 inches of H_2O.

65. A system according to any one of claims 58 through 61 wherein:

(a) the system is selected from stationary equipment and off-road vehicles; and,

(b) the media construction is constructed and arranged for installation and air cleaner operation over an operating period of normal equipment use, of at least 450 hours, without refurbishing or replacing the primary filter element and without an overall restriction, across the air cleaner, exceeding a selected value between 20 and 30 inches of H_2O.

66. A system according to claim 65 wherein:

(a) the system is selected from stationary equipment and off-road vehicles; and,

(b) the media construction is constructed and arranged for installation and air cleaner operation over an operating period of normal equipment use, of at least 500 hours, without refurbishing or replacing the primary filter element and without an overall restriction, across the air cleaner, exceeding a selected value between 20 and 30 inches of H_2O.

67. A system according to claim 66 wherein:

(a) the selected value, of the overall restriction, that is not exceeded, is 25 inches of H_2O.

68. A system according to claim 67 wherein:

(a) the system includes an engine rated at an engine intake air flow within the range of 680-1200 cfm.

69. A system according to claim 68 wherein:

(a) the system is a truck having a GVW within the range of 19,501-26,000 lbs.

70. A system according to claim 68 wherein:

(a) the system includes an engine rated at an engine intake air flow demand within the range of 1000-1660 cfm.

71. A method comprising:

(a) operating an on road vehicle comprising a system in accord with any one of claims 1 through 31 for at least 40,000 miles without:

(i) changing or refurbishing a primary filter element therein; and,

(ii) reaching an air flow restriction, across the air cleaner, of greater than 30 inches of H_2O.

72. A method according to claim 70 comprising:

(a) operating an on road vehicle comprising a system in accord with any one of claims 1 through 31 for at least 40,000 miles without:

(i) changing or refurbishing a primary filter element therein; and,

(ii) reaching an air flow restriction, across the air cleaner, of greater than 25 inches of H_2O.

73. A method of filtering engine intake flow to an engine having a rated air flow of at least 370 cfm; said method including a step of:

(a) providing a primary filter element, operably positioned with respect to engine air intake flow, having a media volume of no greater than the rated engine air intake flow in cubic feet per minute divided by 1369 $min.^{-1}$.

74. A method of servicing an engine intake air cleaner of a system having a rated air flow of at least 370 cfm; said method including a step of:

(a) providing, in the air cleaner, a primary filter element sized to have an approach velocity of at least 440 fpm under a rated engine air flow for the system;

(i) the primary filter element including a media pack having a media construction thickness of no greater than 2.5 inches;

(ii) the primary filter element being further characterized by:

(A) an overall operating efficiency of at least 99.5%, when evaluated by SAEJ726; and,

(B) a media construction including:

(i) an upstream depth media portion; and,

(ii) a pleated barrier media construction positioned downstream from the upstream depth media portion.

75. An air filter element comprising:

(a) a media pack having first and second ends and defining an open filter interior; said media pack including:

(i) an inner liner; and,

(ii) a media construction positioned upstream of the inner liner;

(b) a first, open, end cap positioned on said media pack first end;

(c) a second end cap positioned on said media pack second end;

(d) an adapter ring having a central cylindrical wall structure having an inner surface and a positioning structure;

(i) said adapter ring being positioned with said central cylindrical wall structure supported in extension into said open filter interior and with said inner surface spaced at least 0.5 inch from said inner liner; and

(ii) said positioning structure securing said adapter ring to said media pack first end with a portion of said positioning structure embedded in said open end cap; and

(e) a sealing ring positioned in said open filter interior and in covering relation to said inner surface of said central cylindrical wall structure.

76. A method of designing a reduced size filter element for a system having an engine intake air flow of at least 370 cfm; said method including a step of:

(a) determining a media volume occupied by a conventional pleated element for the system;

(b) calculating a reduced media volume by determining 66% of the media volume from step (a);

(c) determining an inside diameter for the conventional pleated element of step (a); and,

(d) constructing the reduced size element by:

(i) selecting as an inside diameter, the inside diameter of step (c);

(ii) selecting as a media volume, a volume no greater than the media volume of step (b);

(iii) selecting as a media thickness, a media thickness of no greater than 2.5 inches; and,

(iv) creating a media construction, for the primary element, including:

(A) an upstream depth media portion; and,

(B) a pleated barrier media construction positioned downstream from the upstream depth media portion.

77. The primary filter element constructed and arranged for use in a system according to any one of claims 1 through 70.

FIG. 1

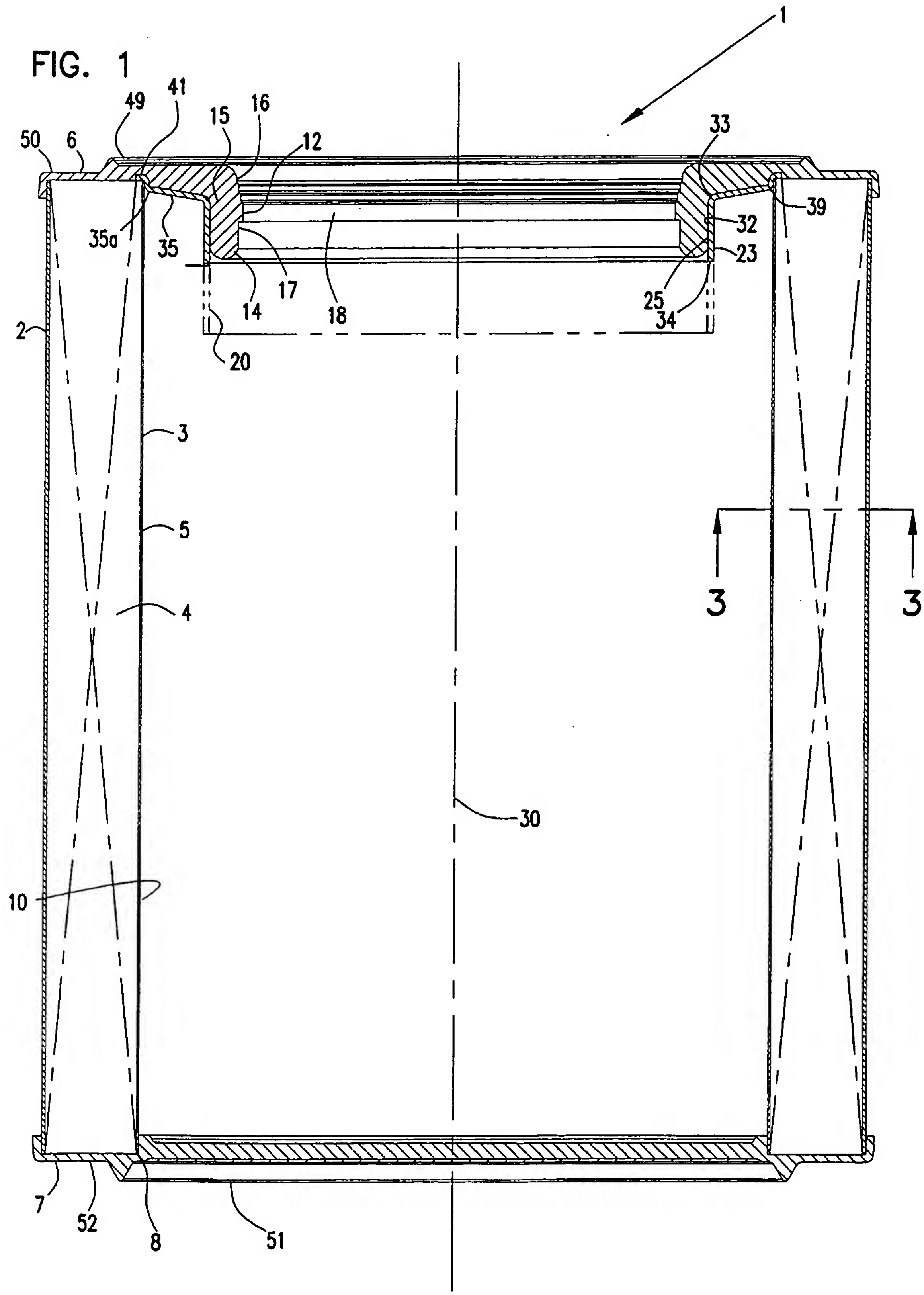
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FIG. 2

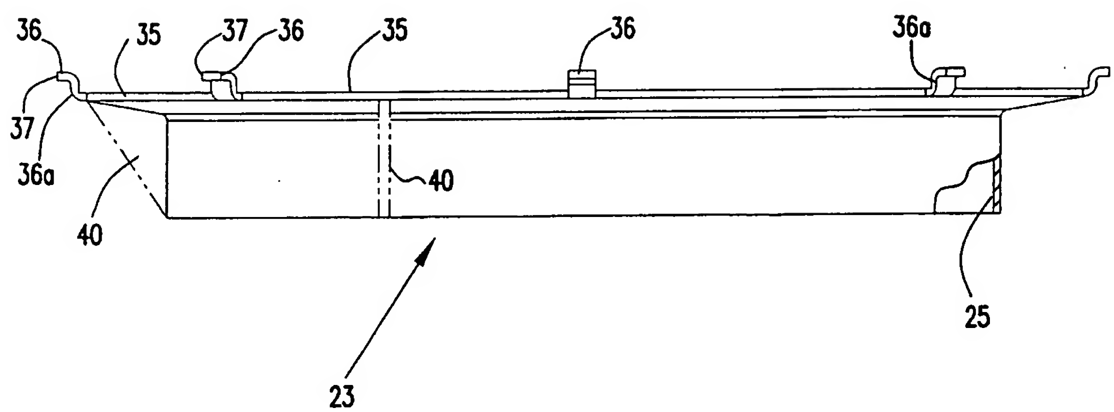

FIG. 2A

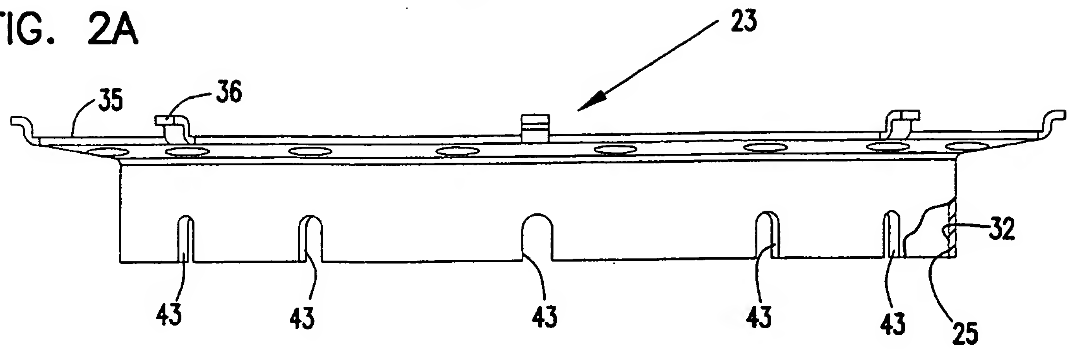

FIG. 2B

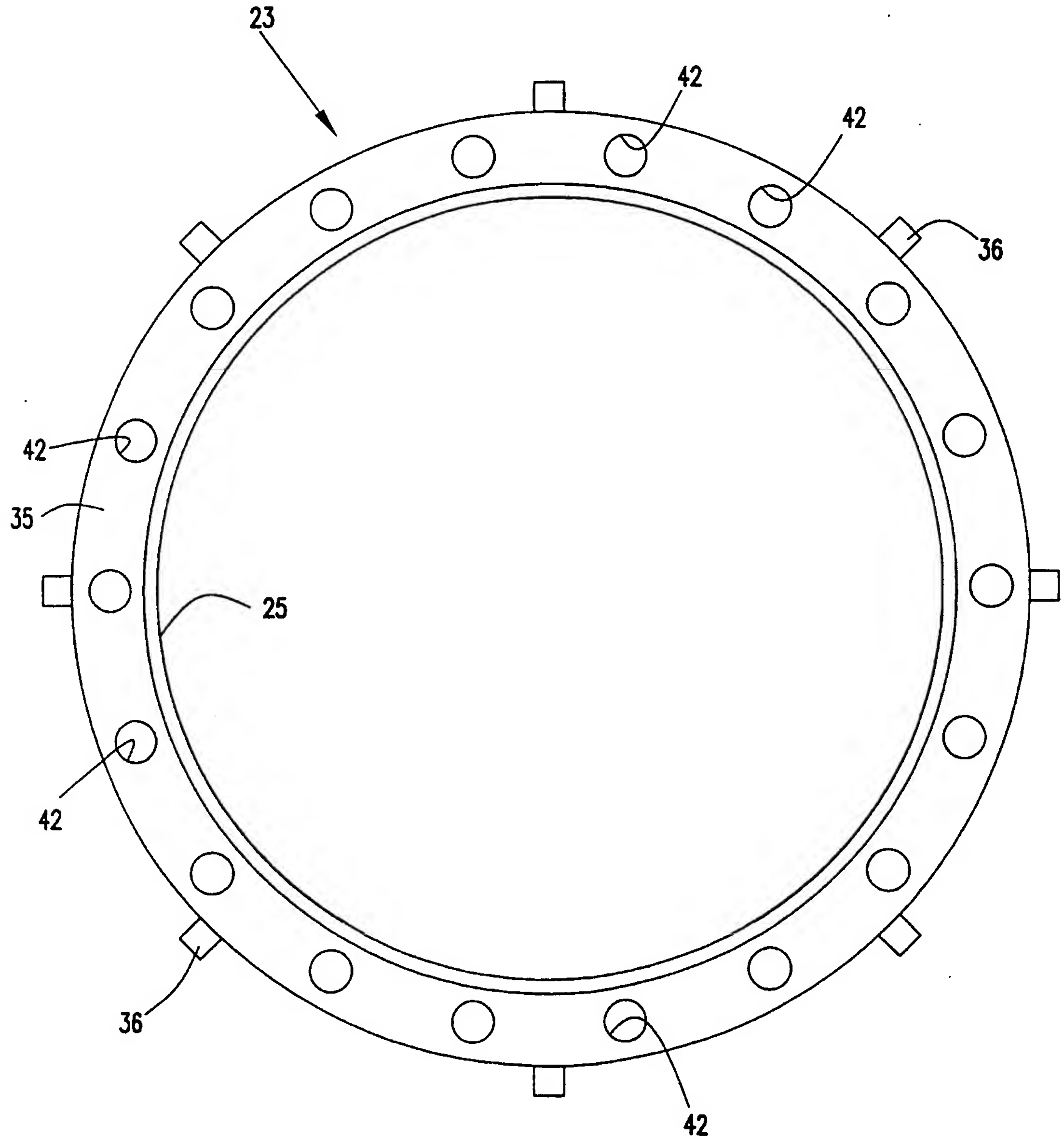

FIG. 3

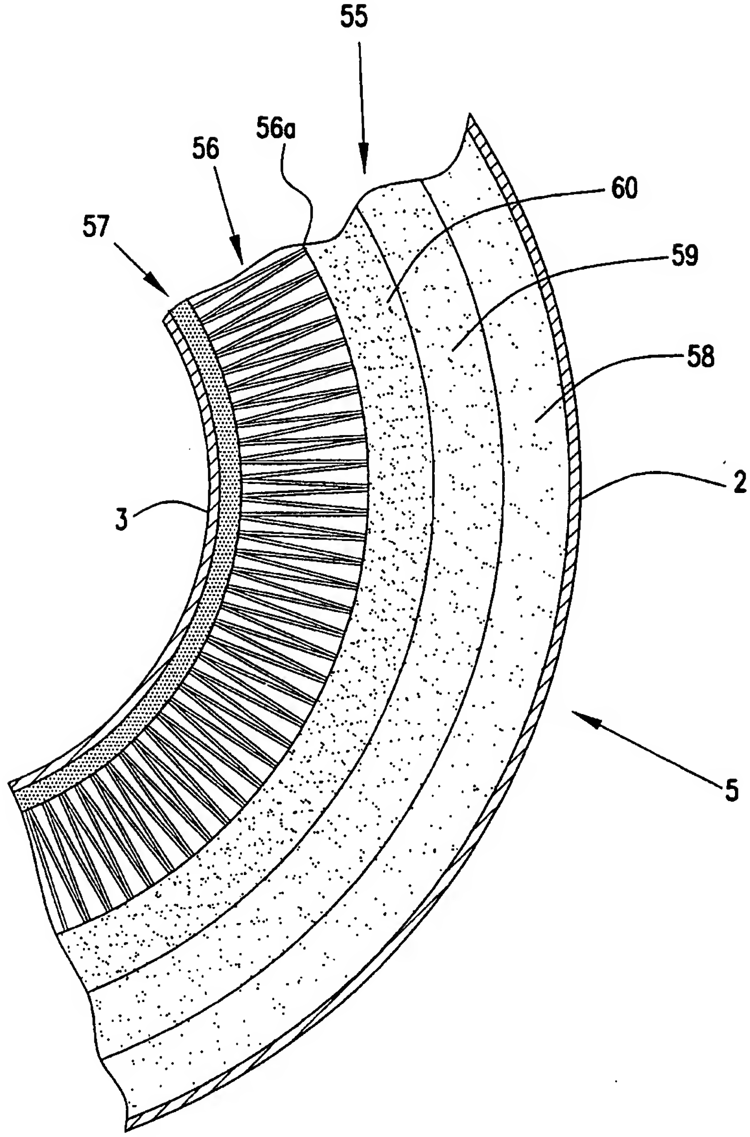

FIG. 4

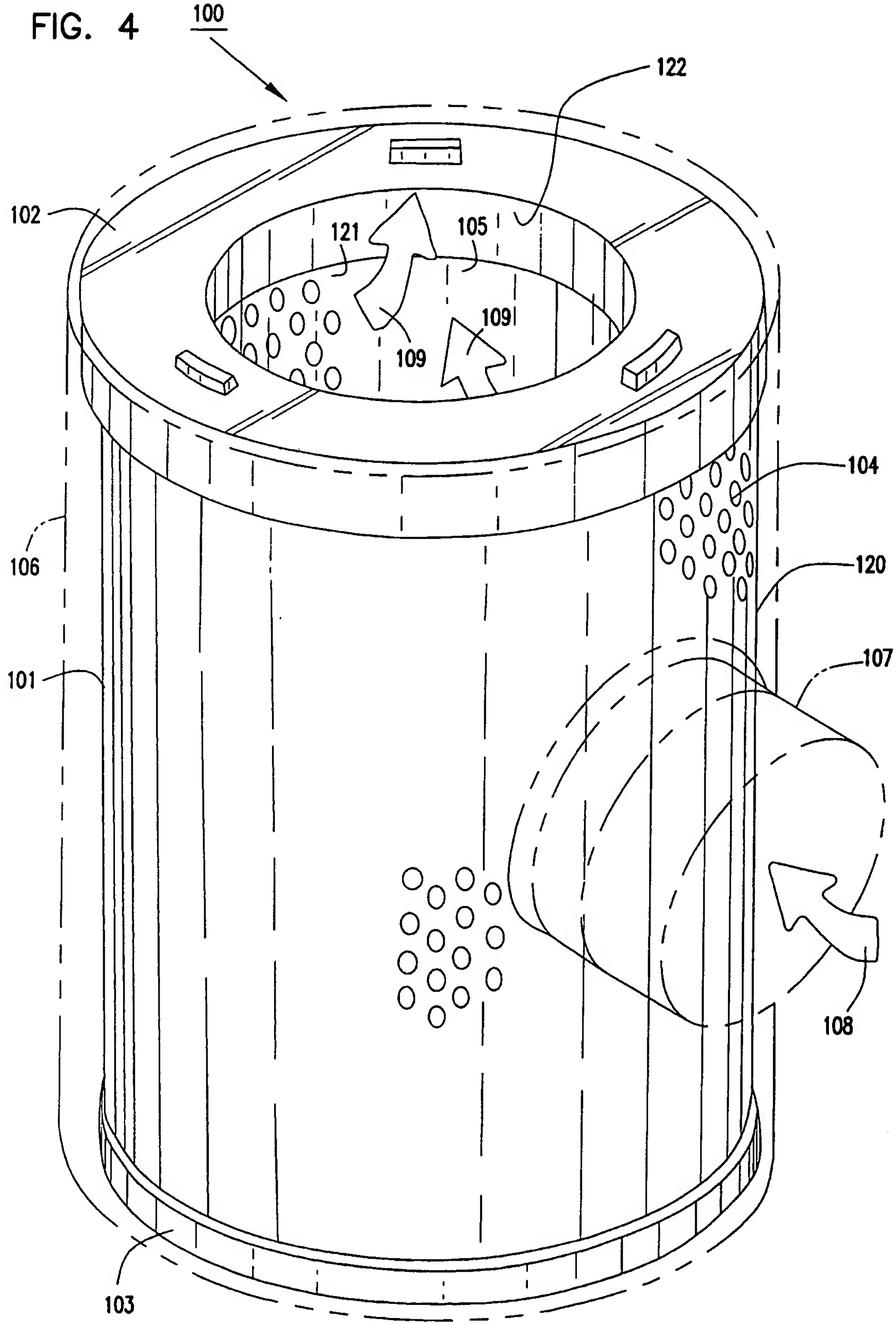

FIG. 5

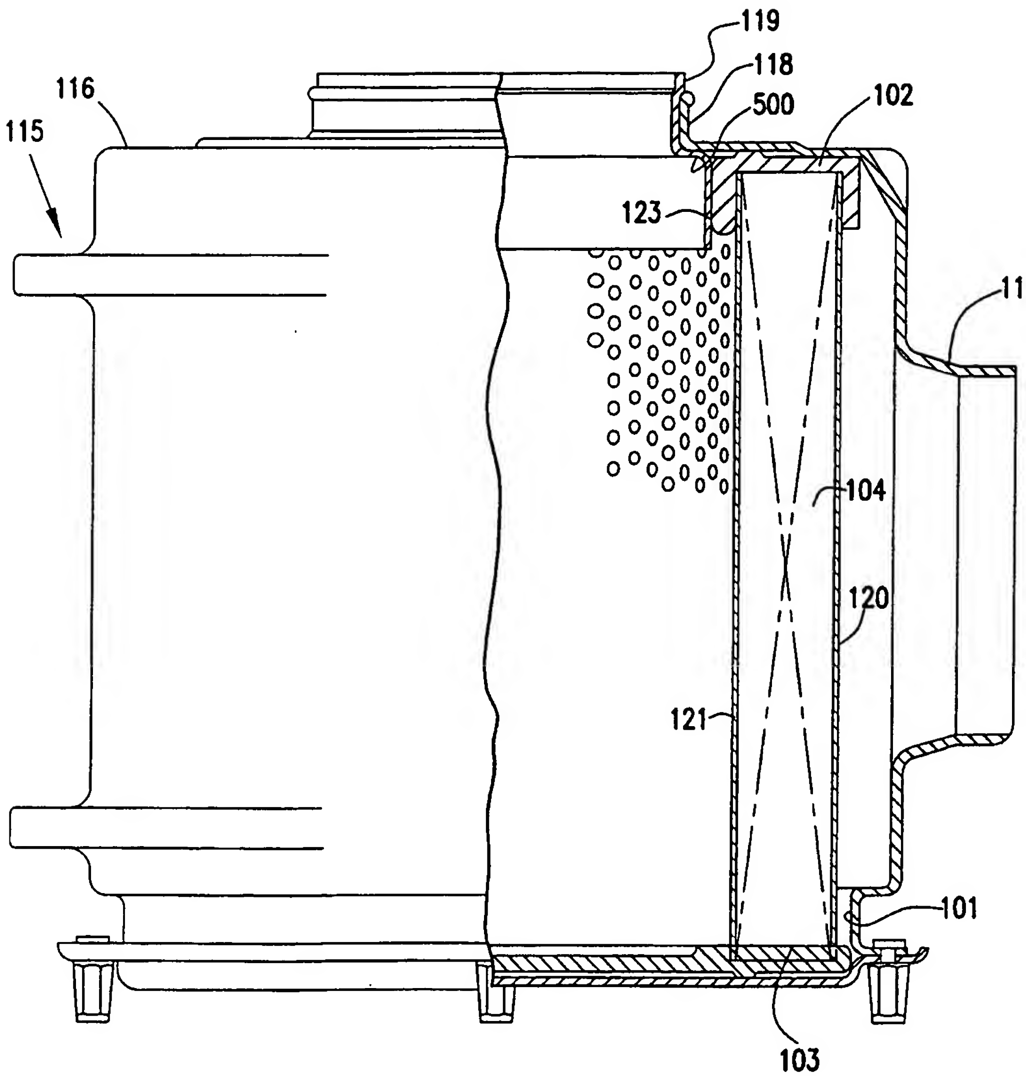

FIG. 6

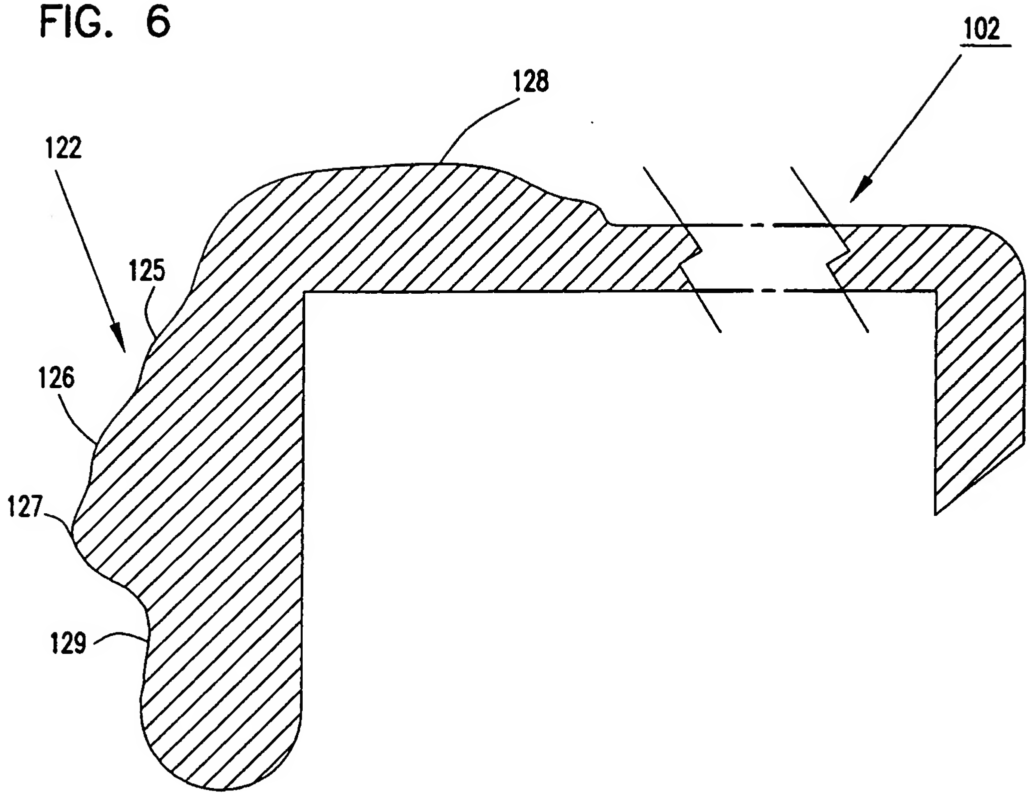

FIG. 7

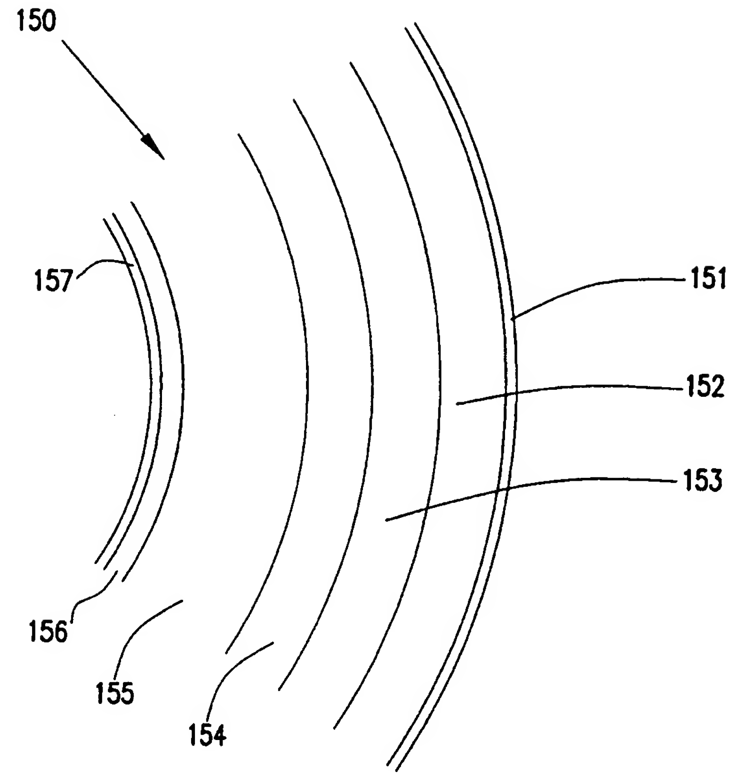
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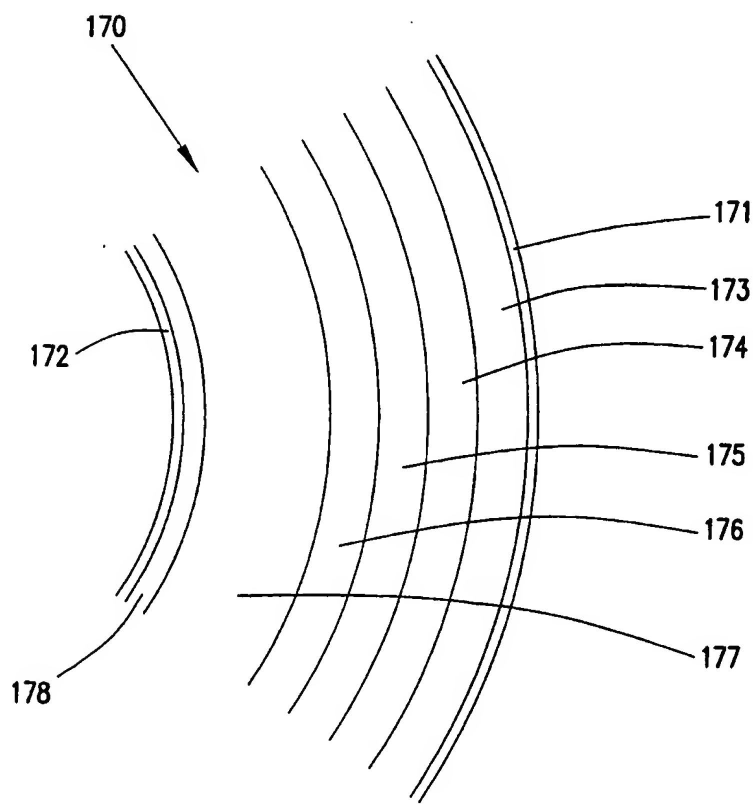
FIG. 8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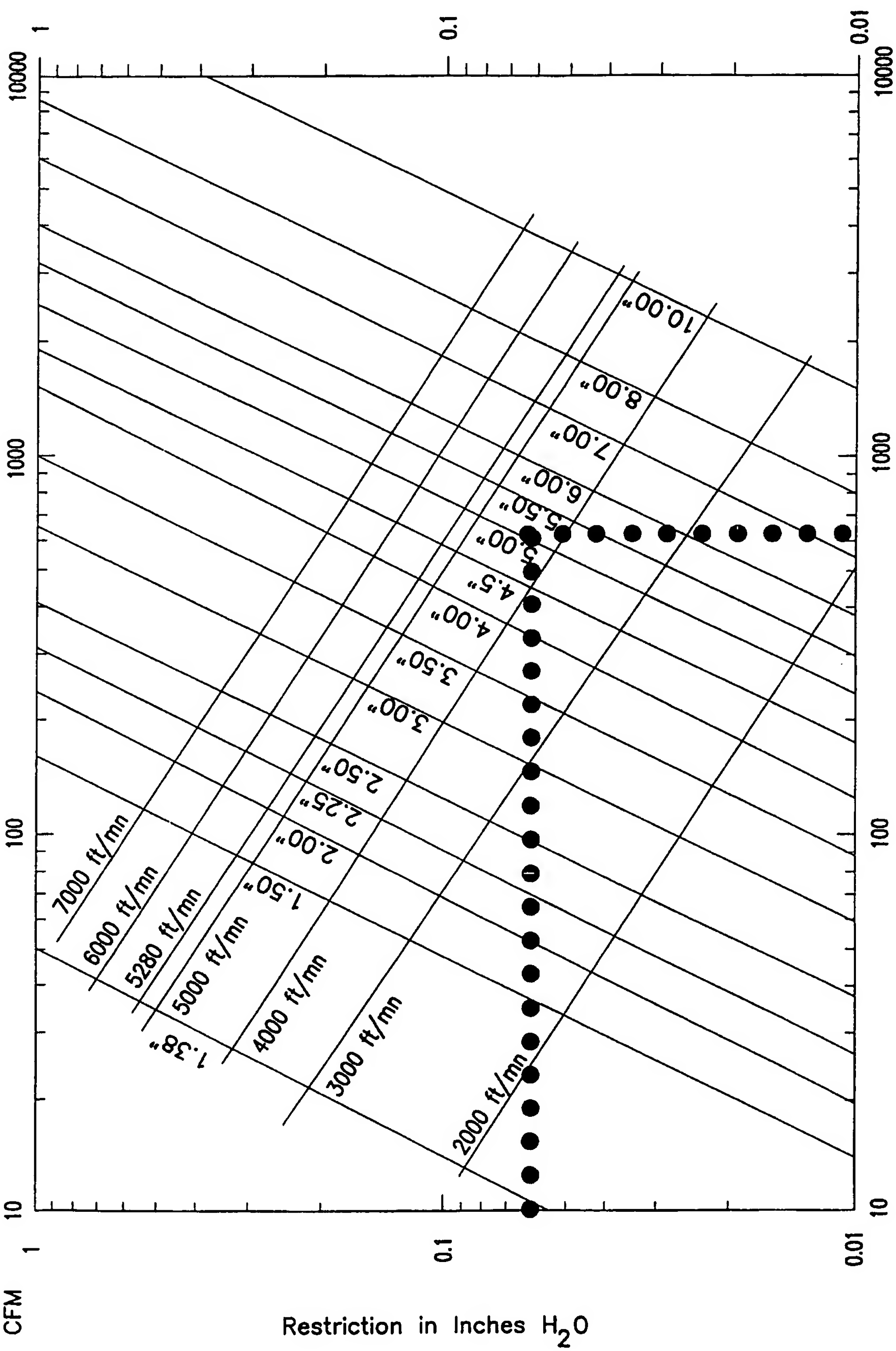
CFM
Restriction in Inches H_2O
10000
1000
100
10
1
0.1
0.01
7000 ft/mn
6000 ft/mn
5280 ft/mn
5000 ft/mn
4000 ft/mn
3000 ft/mn
2000 ft/mn
1.38"
1.50"
2.00"
2.25"
2.50"
3.00"
3.50"
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7.00"
8.00"
10.00"

FIG. 9

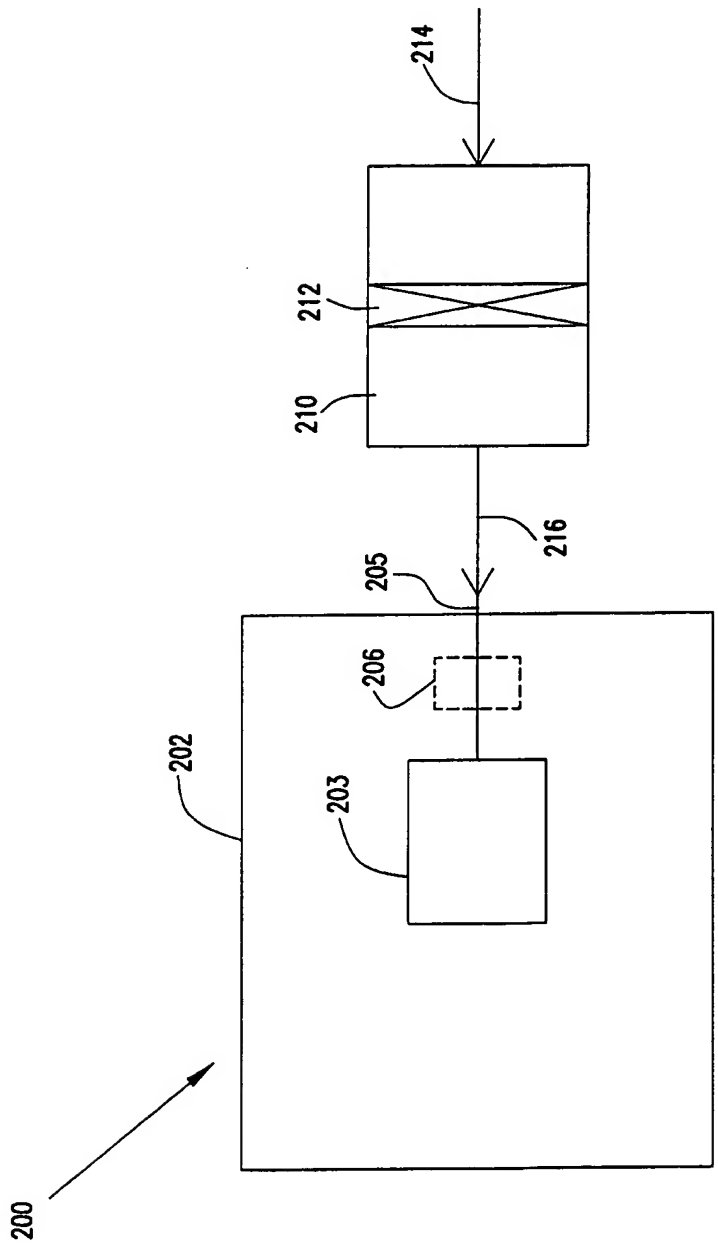

FIG. 10